# Maintaining Future Military Aircraft Design Capability

Jeffrey A. Drezner, Giles K. Smith, Lucille E. Horgan, Curt Rogers, Rachel Schmidt





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A Project AIR FORCE Report prepared for the United States Air Force

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# PREFACE

Recent indications of severely reduced development and procurement budgets for military equipment have aroused concern about the continuing viability of the defense industrial base. RAND is engaged in a series of studies focused on several aspects of this general topic. One issue being addressed is the future capability of the U.S. aircraft industry to design and develop advanced military aircraft. Even before recent shifts in world political postures, trends in DoD budgets seemed likely to lead to a decrease in the number of firms specializing in military aircraft or to otherwise weaken the associated industry infrastructure. This study examines the extent of the possible problem and begins to explore some policy options that might alleviate it.

This Report provides the results of the initial phase of the study, which defined design capability and identified some risks to future military aircraft design capability. The authors have also developed a conceptual framework for examining possible solutions. An earlier version of these results was briefed to the Air Force Advisory Group in April 1991 and to several other audiences in industry and government through the second half of 1991.

This research began in January 1990 and was sponsored by the Office of the Assistant Secretary of the Air Force (Acquisition). It was performed as part of the Resource Management and Systems Acquisition Program within Project AIR FORCE.

# SUMMARY

If present trends toward reduced force size and equipment buys continue, will the military aircraft industry be able to respond in an effective and timely manner to the nation's future defense needs? This research addresses one element of this broad issue: the continuing ability to design and develop manned aircraft systems. Many studies and review committees have examined the *industrial base,* focusing primarily on the ability *to produce* items under various conditions. Other studies have examined the organization and funding of the underlying *technology base*. But having the basic technology and a production base does not ensure the ability to design and develop a new system in an effective manner. Although other studies have examined weapon system development in terms of acquisition strategies, we were surprised to find that little attention has been devoted to the design and development process with respect to industry posture and capability. It is this design capability, as affected by diminishing budgets and new project starts, that is the focus of this research.

Our basic goal was to determine if action was necessary in the near term to maintain future military aircraft design capability. Specifically, our objectives were to: (1) identify and quantify factors and trends potentially affecting design capability, and (2) develop a conceptual framework for examining possible solutions to the problems we identify. There are two ways in which current and projected trends could pose problems. First, a radically decreasing business base could force a reduction in industry size, possibly past some threshold required for an effective response to Air Force needs. Second, the quality of design capability in those firms remaining in the industry could be degraded, with cost, schedule, and performance implications for future aircraft programs. We examined both of these issues.

Our approach included documenting historical trends in research, development, and procurement budgets; production histories; new program starts; and industry size, structure, and financial viability. We identified and quantified the resources necessary for maintaining design capability through a formal survey of several current aircraft prime contractors and through numerous interviews with government and industry officials involved in various aspects of aircraft design and development.

We first defined *design capability*. As currently structured, military aircraft design capability resides within the relevant division of a larger firm. Our research indicated that maintaining an adequate design capability has historically required: (1) a sufficient number of design organizations to sustain a competitive posture, (2) an adequate experience and skill base within each of these organizations, (3) a sustained program of technology development to provide the foundation for future performance advances, and (4) a business environment to ensure that the other three items can be achieved.

In view of the diminishing budgets, we were especially interested in defining the minimum resources that a firm has to preserve in order to generate a competitive bid on a new design. We assembled a useful amount of data on several design organizations over the past several decades (staff size and composition, facilities needed, funding levels, organizational structure, etc.) and matched those with project activities. The data were remarkably consistent, giving us confidence in our definition of the type of resources required for aircraft design. Historically, the minimum size of a viable design organization is characterized by an annual budget of about $100 million and about 1000 engineers and technical managers. Several types of facilities are also required, ranging from advanced composites labs to wind tunnels to radar ranges. Additionally, an institutional structure that links funding, staff, facilities, and technology together is an important design capability resource. Such a core design team provides the foundation for a new design activity.

Given this aggregate definition of design capability, we then examined projected future environments to see if there was any danger of falling below a desired capability level in any of the critical areas. Thresholds could be exceeded if the resources that enable design capability cannot be adequately supported or if the quality of that capability becomes degraded.

In particular, we examined trends in system costs, development and production budgets, number of projects, industry size and structure, and acquisition policy. We found that there will probably be enough business in the foreseeable future to sustain several aircraft companies in a sufficiently healthy state so that they will choose to remain in the military aircraft design business. That does not mean all of the present industry posture will remain. Currently, there are ten firms or major corporate divisions whose main business is designing and producing manned military aircraft. The number of such design organizations has been slowly shrinking for some time (from 15 to 10 since 1960), and we expect additional consolidation over the next 10 to 20 years. It seems unlikely, however, that enough firms will choose to leave the business in the foreseeable future to cause concern about the overall capacity (both development and production) of the industry.

The issue of maintaining an adequate level of design staff experience and skill is more troubling. Designing a new aircraft system requires a high level of both technical and management skill, as well as more routine engineering capability. As with any creative endeavor, the necessary skills are honed through practical applications as well as formal training. An aircraft design team, no matter how qualified and well supported, will inevitably lose its overall ability to produce new aircraft designs that incorporate advanced technologies if it goes too long without actually designing, flying, and testing a new aircraft.

What is the rate of design activity needed to maintain an adequate experience base? We cannot define the exact value, but we believe there are indications that the activity rate for many aircraft design teams has already fallen to an undesirably low level. Budget and force structure trends suggest that it will fall even further over the coming decade, assuming no change in industry structure or acquisition policy and practice.

Projections of the number of active design organizations and the number of new aircraft design starts through the remainder of this decade lead us to believe that the quality of future design capability is at risk. Projected activity rates seem unlikely to support an adequate experience base for future engineers and designers if that design activity is distributed across the present ten firms or divisions. In the 1950s, 49 new aircraft reached the flight test stage, an average of 2.5 new designs per organization in that decade. In the 1990s, we can expect at most six new designs (YF/F-22, YF-23, X-31, C-17, and possibly an AX and the X-30 NASP). That implies that in the 1990s, the ten design organizations will design less than one new aircraft each, on average. Additionally, low activity rates and budgets seem unlikely to provide opportunity, ability (funding), and incentives to invest in technological advance and facility modernization. In short, there are too many firms chasing too few dollars and programs. If nothing is done to address this problem, the future quality of design capability is very likely to be degraded, with serious implications for the cost, schedule, and performance of future aircraft.

The problem of maintaining the quality of future design capability is multidimensional, as quality requires an adequate experience base, an active technology base, and the infrastructure (academic institutions, government labs, facilities, and management organizations) that ties it all together. Projected decreases in budgets and activity rates ultimately threaten all aspects of design capability, though the more urgent near-term problem concerns the experience base we are providing our future designers. Thus, effective solutions to the problem will also be multidimensional.

We also discovered that concern for sustaining a design capability is not reflected in DoD policy documents or organizational charters. Design capability has no institutional advocate.

There are many strategies that might help resolve the problems posed by the changing environment of aircraft design. For instance, the government could change acquisition policy and practice by increasing the number of development activities—including some that are not necessarily committed to production—or assuming some of the technology development and early design activities currently performed by industry. Alternatively, the government might take a more aggressive approach through source selection decisions and financial incentives in order to guide the behavior of firms in the industry. Of course, if the government takes no action, industry will still respond to market forces and trends in the acquisition environment, but perhaps not in a way that most effectively preserves design capability.

We conducted a very preliminary review of some of these options, particularly expanding the range of design activities to include an occasional technology demonstrator or system prototype that is not committed to production, a practice that would require a shift in the way both government and industry approach system acquisition. This alternative is multidimensional in that the policy changes required to successfully implement it touch on financial viability (e.g., allowing profits from R&D work) and technology base and infrastructure concerns, as well as its direct effect of increasing design team experience.

We believe that the declining experience base of aircraft design teams poses a serious enough threat to U.S. defense capability that the problem—and its possible remedies—should be given close attention. Although a full set of remedies cannot be defined at this time, some individual strategies seem appropriate. At a minimum, we recommend elevating this issue to a higher level of visibility within DoD and considering issues associated with design capability as part of acquisition policy and program decisions. It also seems appropriate that government should not intervene in the inevitable industry consolidation that will take place as a result of the changing acquisition environment. In particular, firms considering leaving the industry should not be artificially enticed to remain prime contractors.

## ACKNOWLEDGMENTS

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Additionally, the many industry and government officials we talked with during the course of this study deserve much thanks. This research would not have been possible without the cooperation of the firms who provided data on their aircraft divisions and the government and industry officials who provided their views of the problems and critiques of some of our early ideas. The key organizations are listed below.

Any errors of omission are solely the responsibility of the authors.

INDUSTRY:

General Dynamics, Fort Worth Division

Lockheed Aeronautical Systems Company

Lockheed Advanced Development Company

Northrop Aircraft Division

Rockwell, North American Aircraft

GOVERNMENT:

Aeronautical Systems Division, Air Force Systems Command

Defense Advanced Research Projects Agency

U.S. Congress, Office of Technology Assessment

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# 1. INTRODUCTION

## BACKGROUND

After peaking in the mid-1980s, the United States defense budget has declined substantially, and some projections call for additional decreases throughout the coming decade. This has raised widespread concern about the general health of the U.S. industry that supports defense needs. Will the inevitable contraction of that industry cause problems in terms of its ability to respond to defense needs in the future? This question becomes particularly pressing when applied to those elements of the industry whose product lines are uniquely military; that is, firms (or defense-related divisions of diversified firms) whose only customer is the Department of Defense (DoD). Conceivably, it could be in the national interest for the DoD to take special measures to ensure the continued viability of certain sectors of the industry. At the very minimum, it seems reasonable for the DoD to avoid near-term actions that might unnecessarily diminish future capabilities of key industrial sectors.

This study is an assessment of such issues with respect to one product line: manned military aircraft. Military aircraft present several characteristics that seem to justify such an assessment at this time:

- They are a major element of our national defense posture.
- Their military value depends strongly on cutting edge technologies.
- The aircraft themselves, and many of the underlying technologies, have few markets besides the DoD.[1]
- The lead time to develop and produce such aircraft, including the development of the advanced technologies necessary for each new generation, is measured in decades.

Thus, it seems prudent to look into the future and identify, to the extent possible, any trends that might affect the ability of the U.S. military aviation industry to respond effectively to future needs for new aircraft designs.

[1] An interesting question is whether the government will institute policies that enable prime contractors to design and develop aircraft for foreign markets, or whether foreign military sales will always be based on existing designs currently in DoD inventory. While foreign military sales of either type are potentially important to the issues examined in this research, we have not explicitly considered them here.

A review of existing literature on the general topic of the defense industrial base yielded two interesting results. First, despite a rather large body of work on the technology base, and on production activities (capacity, efficiency, surge capability, etc.), we found almost nothing dealing with the design process in terms of institutional structure, measures of activity level, resources required, or any such aggregate descriptors needed for a study of this type. There was an occasional paper on the need to recognize "design" as a specific engineering discipline, especially in terms of college curricula, but most of the literature was devoted to project-specific or technology-specific topics. We found little evidence of prior research on the subject of design and development capability, both in general and specifically for aircraft.

A second result of the literature review was the noticeable lack of formal DoD policy that reflected any intent to consider the strength or quality of industry aircraft design capability. Considerable policy attention is directed toward the *results* of the aircraft design process and toward broad strategies for managing such processes, but none is directed toward ensuring the continuing ability to *perform* such a process.

We are not suggesting that there are no DoD policies that affect aircraft design and development capability. In fact, a wide range of acquisition policies and practices have important effects on design capability, particularly financial (progress payments, profit policy, etc.), contracting, and technology base policy. However, these policies have goals other than maintaining or enhancing design capability, and their effects on design capability are both invisible to decisionmakers and uncoordinated across policy areas and agencies. The rapidly changing acquisition environment—increased threat uncertainty, decreasing budgets, increasing system costs and complexity, fewer new program starts, and smaller total quantities—suggests that reexamining this gap in acquisition policy is prudent at this time.

## STUDY SCOPE AND OBJECTIVES

In this study, we examine whether the industry will continue to be able to design and develop advanced military aircraft in an effective manner. The scope of our research includes all fixed-wing military aircraft used by any of the services except executive transport and primary trainers.[2] Design and development cannot be easily isolated from the broader process of building military aircraft, including the preceding phase of developing advanced technologies and the later phase of carrying out full-scale production. While the design process represents a specialized set of resources that are not necessarily sustained by either technology base or production activity, there is significant overlap with both the earlier and later phases. Thus, the scope of this study necessarily includes some technology base and production considerations.

Our basic objective was to determine if action should be taken to ensure future industry capability to design and develop advanced military aircraft. Specifically, we attempted to:

- define and quantify any effects on design capability resulting from changes in the acquisition environment, and
- develop a conceptual framework for identifying and evaluating policy options to address these effects if they are a problem.

There are two ways in which recent trends might adversely affect future design capability. First, over the long term, a deteriorating business base could force exit from the industry, resulting in an industry size that is below some desired threshold. In the extreme, when the Air Force requires a new advanced aircraft in 20 or 30 years, there could be no aircraft design organizations that could respond effectively. Second, the trends might affect the quality of the design capability possessed by those firms that do remain in the industry. This research addresses both of these issues and develops a conceptual framework for examining possible solutions to the problems we identify.[3]

## APPROACH

The issue of maintaining aircraft design and development capability was approached from several directions. We surveyed the available literature, obtained contractor data via a formal questionnaire, interviewed contractor and government personnel, conducted a study of how new technology is incorporated into the design process, and de-

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[2]Highly classified special-access programs have been excluded from the study because information on their existence and characteristics is not readily available.

[3]A current research effort is performing a thorough analysis of the costs and benefits of alternative strategies.

veloped historical profiles of government, industry, and company-specific measures related to design capability.

A review of existing literature showed that the issue of design capability has never been directly addressed through focused research or policy guidance. Nonetheless, the literature provides a wealth of information on specific acquisition policies and practice affecting the technology base, weapon system development, and production concerns. Such information provides a context for the rest of the analysis. A bibliography of selected documents is included in this Report.

We surveyed several aircraft prime contractors to better understand the types and magnitudes of resources involved in designing and developing military aircraft. We collected data on personnel and research and development funding for the aircraft division(s) of the firms and for their specific aircraft projects.

Additionally, we held many discussions on a more informal basis with industry and senior government officials involved in military aircraft design and development. Within industry, we interviewed over 40 individuals, mostly at the level of vice president, program manager, and chief engineer for specific aircraft programs. On the government side, we interviewed knowledgeable officials within the Air Force laboratories, the Aeronautical Systems Division of the Air Force Systems Command, the Defense Advanced Research Projects Agency (DARPA), and the Office of Technology Assessment. These discussions provided us with a sound basis for drawing conclusions on what the current set of participants thinks is important in terms of design capability and the factors and trends that affect it.

Technology base issues are an integral part of the issues addressed in this research. A vigorous technology base that continually advances the state of the art is a critical component of design capability. We conducted a detailed case study of advanced composite materials, one of several new technologies recently introduced into aircraft design that are fundamentally changing both the process and product. That effort improved our understanding of the various government, industry, and academic institutions that have important roles in technology development and application, and provided insights regarding the length of time and amount of funding required for an innovative idea with potential utility to become a practical application.[4]

[4]Detailed results of the composites case study have been published separately. See Curt Rogers, *Advanced Composite Materials: The Air Force's Role in Technology Development*, RAND, N-3503-AF, forthcoming.

To develop a basis from which to project how the aircraft industry is likely to respond to changes in the acquisition and business environment, we documented some of the more important long-term trends in acquisition. These trends include changing policy concerns, increasing system costs, decreasing development and production budgets, and declining numbers of active development and production programs. We also assessed the general economic health of the aircraft industry at the prime contractor level using data contained in their annual reports and other standard financial reporting documents. That assessment tracked trends in aircraft sales, R&D funding, profit, and debt for the seven aircraft prime contractors. This effort provided insight into the overall financial viability of the aircraft industry and the factors that affect industry's behavior.

## REPORT OUTLINE

This study is organized around the specific research questions we addressed. In Section 2, we define the elements of a design capability and the organization in which such a capability is housed, and then assess the resources required to maintain that capability. In Section 3, we examine a variety of trends in the acquisition environment with the potential to affect design capability. These include budget levels, number of active production lines, frequency of new program starts, and contractor profitability. Section 4 discusses the implication of those trends in terms of industry size and the quality of design capability. Section 5 presents a conceptual framework for examining alternative policy responses that could influence the future state of design capability. A brief exploration of two possible options—increasing design activity rate and industry teaming—illustrates many of the issues raised earlier in the analysis.

## 2. DESCRIPTION OF DESIGN CAPABILITY

To evaluate the health of the aircraft design resources in the United States, and to identify any major trends affecting those resources, we first need to be more specific about exactly what constitutes an *aircraft design capability*. What resources are required and in what amounts? What kind of organization is required? How do the resources and organization interact? What kind of activities are part of that interaction? This section addresses these questions from a historical perspective.

The process of designing a new military aircraft involves many organizations, ranging from the senior levels of the DoD, where future needs are articulated, down to hundreds of specialized firms that provide the many components needed in the new design. In this study, we focused on the *prime* contractor: the firm that plays the central role in marshaling all the industry resources and that is, typically, the single agent contractually obligated to produce the design.[1] Perhaps the most important function of the prime contractor is that of system integrator, linking all the subsystems together so that they function as a coordinated system.

At the present time, there are seven firms in the United States that function as prime contractors for the development of military aircraft. Three of those firms have more than one military aircraft division, yielding a total of ten organizations capable of acting as prime contractor for aircraft design and production. It is these ten design organizations that are the focus of this study, rather than the parent firms. Several of the parent firms are highly diversified (e.g., Boeing, Rockwell), and military aircraft does not represent the dominant portion of their business base. Since we are interested in the design and development of military aircraft, individual military aircraft divisions are considered as self-sustaining units.

A list of those ten divisions, together with their current major projects in both the design and production phases, is shown in Table 2.1. Most of these divisions have only one or two product lines, making their business base highly vulnerable to termination of even one program.

[1]We recognize that trends in the acquisition environment that affect prime contractors will also affect the lower tiers of the industrial base, perhaps even more severely. While that is an important issue, it is beyond the scope of this study.

**Table 2.1**

**Current Aircraft Prime Contractors and Major Programs**

| Contractor | Design and Development | Production |
|---|---|---|
| **Boeing** | | |
| Military Airplanes Division | F-22 | B-2 |
| **General Dynamics** | | |
| Fort Worth Division | F-22, X-30 | F-16 |
| **Grumman** | | |
| Aircraft Systems Division | X-29 | F-14 |
| **Lockheed** | | |
| Aeronautical Systems Company | F-22 | C-130 |
| Advanced Development Company | | |
| **McDonnell Douglas** | | |
| McDonnell Aircraft Company | (YF-23), T45TS, X-30 | F-15, AV-8B, F/A-18 |
| Douglas Aircraft Company | C-17 | C-17 |
| **Northrop** | | |
| Aircraft Division | (YF-23) | F/A-18 |
| B-2 Division | B-2 | B-2 |
| **Rockwell** | | |
| North American Aircraft | X-30, X-31 | |

The F-14, F-15, and F-16 programs are all scheduled for termination within the next few years. While the B-2 program is near the beginning of the production phase, continuing support is uncertain.[2] Additionally, current design efforts seem rather thin: Five divisions were involved in a single program, the Air Force's Advanced Tactical Fighter (ATF), throughout most of the 1980s. The recent decision to award the engineering and manufacturing development contract to the Lockheed-Boeing-General Dynamics team (for the F-22) leaves Northrop and McDonnell Douglas with few active major aircraft development programs.[3] The consequences of the declining activity and business base are explored in Section 4.

## OVERVIEW OF DESIGN CAPABILITY RESOURCES

As a first step in quantifying the resources that a prime contractor has historically required in order to perform the design process, we

[2]The B-2 has been limited to a total of 20 aircraft in the president's FY93 budget submitted to Congress in January 1992.

[3]The Navy recently awarded concept exploration contracts of $20 million to each of five teams competing for the medium attack aircraft program. Those teams include different combinations of all seven firms: Grumman, Boeing, and Lockheed; General Dynamics, McDonnell Douglas, and Northrop; McDonnell Douglas and LTV; Lockheed, Boeing, and General Dynamics; Rockwell and Lockheed. The implications of such arrangements are discussed in later sections.

organized the total activity into the following five categories (see Figure 2.1):

- *Technology development.* This includes the technology research and development activities (staff and laboratories) where each firm seeks to advance the state of the art and to achieve the capability to design aircraft with higher performance than that of the previous generation.
- *Engineering and management staff.* These are the technical staff and technical management that, collectively, embody the skills, knowledge, and experience that are at the heart of a design capability.
- *Facilities.* A wide range of facilities is needed, including labs, wind tunnels, and radar ranges. Some of these are owned and operated by the government and some by the contractor.
- *Financial support.* Funding comes from any of three sources: (1) direct government contracts for technology development and systems design work, (2) corporate investment using funds earned from other work, and (3) independent research and development (IR&D), a portion of which is reimbursed by the government through overhead allocations on government contracts.

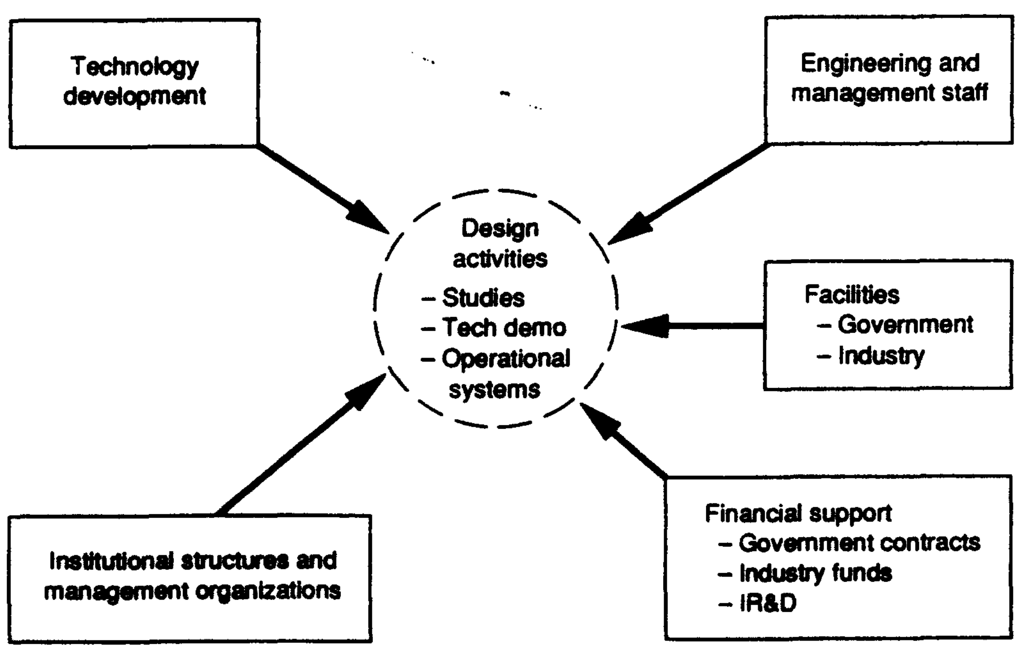



**Figure 2.1—Elements of a Design Capability**

- *Institutional structures and management organizations.* The internal organization of a firm and its relationship to other firms are a critical part of design capability. The management organizations within DoD and how they relate to industry are also important. It is this management structure that brings the other elements of design capability together.

The design activities in which these resources combine range from simulations and analyses (paper-only designs) to full-scale engineering and manufacturing development of operational systems. It is important to note that both government and industry play important roles in each of these resource categories. Though we have chosen to focus on industry, it is the interaction of these resources, both government and industry, through a set of design and development activities that embodies design capability. The products of design capability include both hardware (aircraft) and knowledge (advancing aircraft technologies and their applications).

To better understand the importance of each resource element and, if possible, to determine where critical problems or limitations might be foreseen by the industry, we conducted a survey of five of the ten aircraft divisions shown in Table 2.1. The quantitative data we collected included funding profiles for both the division and its specific projects, a description of its facilities, and personnel profiles in terms of functions, education, and years of experience in the military aircraft industry.[4] Additionally, we held many discussions with the technical managers of both the aircraft divisions and the specific projects within those divisions. Two major themes ran through the questionnaire and interview responses. One was the critical role played by technological advances, and how such basic technological work could continue to be supported and effectively integrated into the design process. A second was a concern over the level of experience available in aircraft design teams. Each of these topics is discussed below in more detail in the context of describing the resources required for design capability.

## TECHNOLOGY DEVELOPMENT

A critical component in the design and development process is the timely maturation of important new aircraft technologies. Incorporation of advances in technology in large part enables the per-

[4]These data are considered proprietary to the firm that provided them and cannot be shown here.

formance increases we desire in next-generation aircraft. If such technologies are not available and understood prior to the start of a new system, design quality may be seriously compromised and the performance of the system will suffer. Only with some understanding of this complex process can effective options be generated for maintaining aircraft design capabilities in the face of declining opportunities for production.

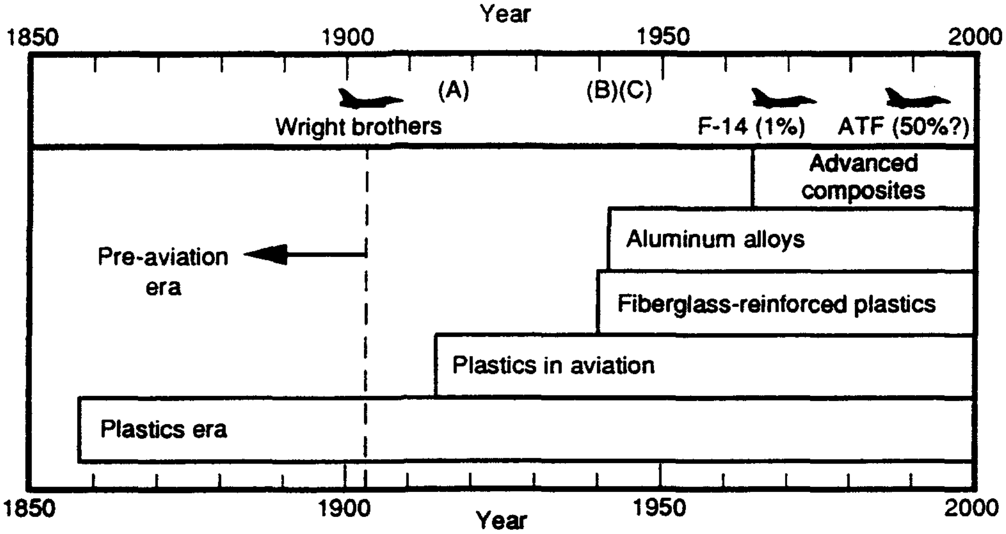
We conducted a case study to better understand how new aircraft technologies are matured, assimilated, and used by design teams. In particular, we investigated the roles that the Air Force and other governmental agencies play in forecasting, initiating, guiding, and funding technologies that are perceived to be of future military importance.

The topic of advanced composite structures was chosen as a model for technology development.[5] Although advanced composites have existed for about 25 years, their unique characteristics are not yet sufficiently well understood to exploit their advantages and guard against their disadvantages over the full range of potential applications. Thus, using these materials requires that new approaches be developed for the design, analysis, and manufacture of military aircraft.

A simplified time line charting the major eras in the development of plastics and composites is shown in Figure 2.2. The beginning of the modern era of advanced composites occurred relatively recently, but in many respects, advanced composites are an outgrowth of several years of research with fiberglass materials. While important materials research on carbon, boron, and other advanced fiber materials was taking place in the late 1950s, the first commercially available material systems based on these fibers did not appear until about 1965. Broad-based R&D programs that sought to apply advanced composites to combat aircraft systems did not begin until that time. Development and application of a new technology like advanced composites take several decades of research and experimentation.

The development of advanced composites must be viewed within the context of the rapidly expanding mission requirements that began to fall within the purview of the Air Force during the late 1950s. At that time, the potential utility of new systems (such as ballistic missiles,

[5]The case study on advanced composite materials has been published separately as Rogers, forthcoming.




(A) Griffith experiment shows high strength of thin, perfect glass fibers and the drastic reductions in strength that occur due to small surface flaws.
(B) Airborne radar demonstration requiring nonmetalic structure.
(C) Supersonic flight.

**Figure 2.2—Plastics and Advanced Composites in Military Aircraft**

supersonic aircraft, and reentry vehicles) was seriously constrained by materials technology. There was a growing realization in the technical and defense communities that advanced materials of all types (e.g., refractory metals, composite materials, ceramics, and plastics) had to be developed if new systems were going to perform adequately in new flight environments.

The opinion of high-level committees that performed state-of-the-art technology assessments (e.g., the National Academy of Sciences) was that the Air Force would find it progressively more difficult to solve its emerging materials problems within the constraints of existing conventional materials and industry capabilities. Because it had the greatest need for this technology, the Air Force was strongly encouraged to take a leading role in the development and application of new materials.

Within this context, the Air Force aggressively pursued the development of advanced composites. In fact, the Air Force performed many critical functions, such as:

- Identifying and advocating the development of a promising new technology.
- Supplying R&D funds for technology development over a sustained period of time.
- Establishing feasibility through technology demonstrations and flight articles.
- Generating initial, nonproprietary, technical databases for the industry to draw upon.

The Air Force took about 14 years (1958–1971) to develop the first truly advanced composite material system (boron/epoxy) from laboratory experiment to validated engineering material appropriate for use in primary aircraft structures. Once reasonable quantities of the material could be produced in the mid-1960s, the Advanced Development Program within the Air Force Materials Laboratory (AFML) funded the development of design and manufacturing capabilities within the airframe industry through a series of flight-demonstration articles. By 1970, boron/epoxy had a significant structural role in a new production aircraft (F-14). Graphite/epoxy, which followed a similar development path, quickly surpassed boron as the advanced fiber of choice.

About five to seven years (1968–1974) of flight experience with demonstration articles and production hardware preceded the beginning of a commitment by the airframe industry to these materials. Firms preferred to be funded to advance technology through direct contract R&D and were reluctant to risk weapon system proposals on new and unfamiliar technology.

In terms of the technology development process, subtier companies—those companies that support the major airframers—play a key role. Two-thirds of the R&D money identified with composites research in the 1966 Air Force Materials Laboratory report on active contracts went to subtier companies; only 30 percent went to the large airframe manufacturers. Much of the research at the subtier level was aimed at further development of the composite materials themselves. Prime contractors hesitated to enter the materials business directly because of the size of investments and materials expertise required. As air-vehicle technologies become more complex, aircraft prime contractors may wish to further emphasize their role as designers and system integrators and, as a result, they may become more dependent on the lower-level companies that supply the various technologies.

Making inferences about the general subject of technology development based on the Air Force's experience with advanced composites is not a simple matter. However, the following points seem important:[6]

- The technology base—government labs, universities, and industry labs—is an important source of new ideas, concepts, and materials that advance the state of the art.
- The Air Force does play a critical role in the identification and development of new air-vehicle technologies; in particular, the technology organizations (e.g., the Materials Laboratory) have important research-management roles, including some support of promising research areas that may not have clear-cut applications at the outset.
- The technology-development process evolves over a period of many years and requires budgetary commitments that may extend far beyond the point of initial applications; in the case of advanced composites, this commitment has lasted for about 30 years and will continue into the future.
- Early identification of and planning for critical supporting technologies could aid in the transition of important technologies from the laboratory to production systems, e.g., manufacturing techniques for composites.

Technology development programs are a critical design capability resource. The underlying infrastructure of the technology base—the links between government, industry, and academic institutions—must be preserved if technology is to continue to advance. Such advance is an important aspect of design capability.

## ENGINEERING AND MANAGEMENT STAFF

The engineering and technical management staff constitutes one of the more important design capability resources. A wide range of skills, experience levels, and functional areas is typically included within a design organization staff. We solicited the views of senior managers on a number of topics related to career progression and the more subtle aspects of how people work together as a team. The results of the questionnaire were followed up by extensive discussions with many of those managers.

[6]These conclusions are more fully supported in Rogers, forthcoming.

## Design Experience Base

All of the industry managers we contacted emphasized that experience in designing, building, and testing aircraft is a crucial asset for design capability.[7] In particular, these senior managers stressed the importance of experience in providing integration and program management skills. Perhaps more important, experience enhances the ability of design engineers to mitigate risk through anticipation of future problems. That view was also expressed in interviews conducted as part of an earlier related RAND research effort, and we verified it in discussions with government officials, including senior Aeronautical Systems Division engineers participating in the management of current Air Force aircraft programs.

Industry officials also asserted that a desirable experience level is not currently being sustained.[8] That problem is likely to get worse, given trends in production activity and new program starts, and is complicated by the introduction of new technologies.

It seems clear that experience is only one element of an ill-defined bundle of skills and capabilities that, in aggregate, determines the overall capability of the design team and the quality of its products. But the experience level of at least part of the design team was clearly the dominant concern of the industry managers as they looked to the future.

To address the issue of experience, we need some insight into at least three questions:

- How important is experience to the overall quality of the design team?
- Experience doing what, and by whom?
- How much experience is needed to meet the test of sufficiency, and how do we measure it?

---

[7]We interviewed over 40 senior industry officials, many at the level of vice president of the aircraft division, advanced technologies, or business development or chief engineer of either a specific project or the aircraft division of the firm. Though there is the potential for bias in the analysis as a result of these discussions, we have been careful to verify as much of the information we were given as possible.

[8]It should be noted that it is the entire design organization whose experience is important, not just that of a few individuals. Continuity and maintenance of a design philosophy or culture unique to a particular design organization are an important part of our current industry structure, providing the basis for a competition of ideas.

While we cannot yet answer any of these questions with great precision, enough information is available to support some general conclusions.

How important is experience? Here we must be guided by the opinions of senior managers in both the aircraft industry and associated government agencies. Their consensus is that experience is crucial to the successful functioning of a design team. A team with an abundance of directly relevant experience (see below) will produce designs consistently superior to those produced by less experienced teams. This assertion clearly needs some experimental verification, but that is hampered by the small number of military aircraft design competitions over the past few decades and by the difficulty in determining the root causes of "failure" by the losers.[9]

Even without quantitative evidence, there seems to be strong intuitive support for the notion that experience is important. Consider the following scenario. A firm starts designing a new aircraft, drawing upon technologies it has developed at least partly in its own laboratories and drawing on the engineering and management skills of its senior people, skills that have been honed through several previous design projects. Suppose that design is successful and enters a long production run, during which time it undergoes occasional modifications and upgrades. However, those modifications and upgrades exercise only a fraction of the skills needed for the original design. Now suppose that 15 or 20 years pass and the team starts a new design. New technologies will have been developed that that team has never utilized in a real design. Many of the senior experienced people who guided the previous design will have retired. The people who have to exercise leadership and make decisions on the new design will find themselves facing severe challenges with very little experience of their own to draw upon. They will inevitably make mistakes, and some of those mistakes could have serious cost, schedule, and performance consequences.

We believe this scenario reasonably reflects the current situation, and that it has contributed to problems both the Air Force and Navy have already experienced in new design projects like the T-46, B-1B, P-7, and A-12. In the course of this research, we obtained anecdotal evidence that the level of experience of design engineers and managers

[9]If the quality and experience level of a team could be directly measured and correlated with source selection decisions, then evidence could be developed that links low quality and experience with losing design competitions. However, a myriad of factors affect source selection outcomes. Further, the quality of design capability has not been an explicit criterion in source selection decisions.

was adversely affecting program outcomes and design quality. However, it is not possible to definitively verify this evidence. A myriad of factors may cause problems in development programs (e.g., technical difficulty, resource constraints, etc.), and it is difficult to isolate the effect of particular factors. Nonetheless, we believe that a declining experience level has been a contributing factor to the problems we observe in many recent aircraft programs.

Answers to the question "Experience doing what?" again depend on the views of the government and industry experts we contacted. Their assertion, critical to the results of the present study, is that to be really good at designing combat aircraft, members of a design team must have had the experience of designing several such aircraft that actually entered the flight-test stage.[10] Paper designs and laboratory development are important, but they are not a substitute for putting aircraft through an actual flight-test program. While good design practices can be, and are, codified through various industry and government manuals and specifications, such documents are not a sufficient substitute for the process of having faced design choices, made decisions, and seen how those decisions turned out in actual flight. A new set of design choices is encountered in each new design so that information captured in databases that reflect previous work can never be sufficient for the task at hand. Intuition, sharpened by experience, still seems to offer the best chance of making a preponderance of good design decisions.

Some have suggested that the application of large-scale computer simulation to the design process will mitigate the need for experienced designers. While simulation and automation of the design process will certainly help, it cannot substitute for the intuition and inspiration that contribute to successful new and innovative designs. Furthermore, such automation is only marginally effective when dealing with new and untried technologies because the basic information needed for the computation algorithms is missing or of low fidelity.

Who needs that critical experience? The consensus seems to be that several hundred of the key people need the experience of past design work. As we discuss later, these key people constitute a core-within-a-core of a base design organization that totals approximately 1000 engineers and technical managers. This group of several hundred key people needs the experience of working together as a team, learning

[10]The issue of transferability of design experience between types of aircraft or other complex systems is discussed in Section 4.

to share responsibilities, and building up mutual trust in terms of individual capabilities and expected performance levels. The organizational culture and design philosophy developed over long periods of time contribute to the quality of a design team's product. Thus, it is difficult to create an effective new design team simply by drawing on individuals from other groups and immediately putting them to work on a new design project. Continuity of experience within a design organization is an important aspect of design experience since it facilitates the teamwork necessary to design and develop a quality product.

Finally, how much experience is needed? The general answer is "more is better," but there is a strong notion that a designer must have completed several designs before he or she has faced an adequate range of design choices and developed an adequate level of experience-based capability to function as a full member of a design team. Based on this notion, we will later devise some approximate measures of design experience.

### Other Characteristics of Personnel

We also gathered data on personnel age and functional distributions for a design organization. Figure 2.3 shows how the age distribution

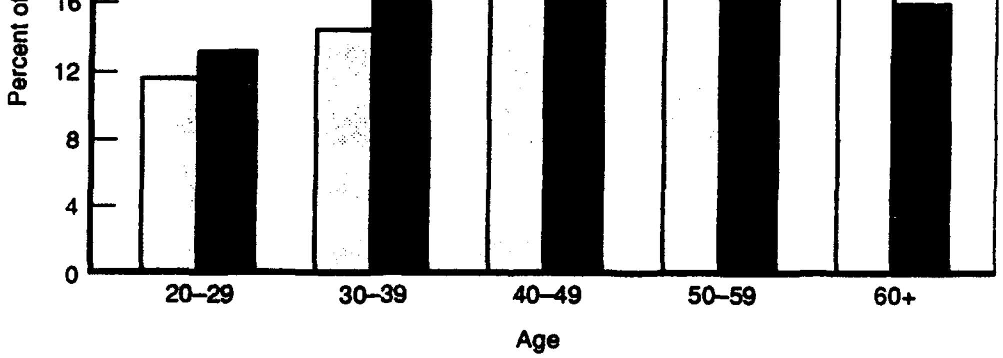
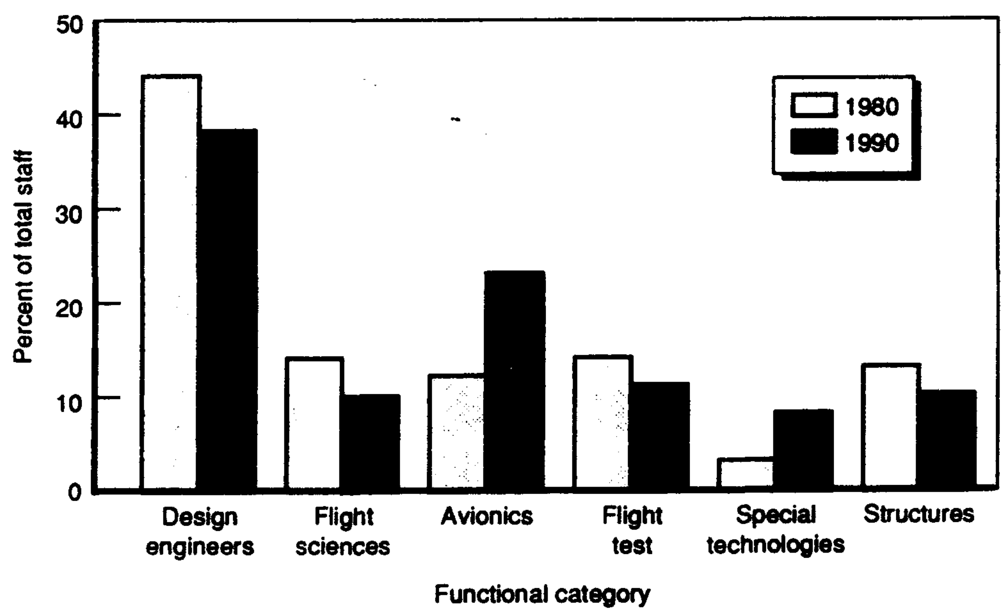



**Figure 2.3—Age Distribution of Design Staffs**

has changed over the last decade. In particular, there is a dramatic increase in engineers in the 30- to 39-year-old age group, hired during the buildup of the 1980s, and a corresponding decrease in the 50- to 59-year-old age group. The distribution in 1990 is becoming bimodel, with peaks in the 30- to 39- and 50- to 59-year-old age groups and a dip in the 40- to 49-year-old age group. This type of distribution begins to get to the heart of the matter: The older engineers with many years of experience on many different aircraft programs are retiring. Their immediate replacements are fewer in number. Future senior technical staff, taken from the 30- to 39-year-old age group, have for the most part worked on only a single aircraft program.

Figure 2.4 indicates that the distribution of functions and skills required within an organization to design and develop advanced aircraft has also changed. More specialists in avionics and special technologies (i.e., low observables) are required. Additionally, the structures group includes proportionately more engineers familiar with advanced composite materials. Interestingly, we found no evidence suggesting that the total number of technical staff needed to design and develop an advanced aircraft has decreased. Instead, increased aircraft complexity—in part due to incorporation of new technologies




NOTE: Based on actual skill mixes of five design organizations.

**Figure 2.4—Distribution of Functional Categories for a Notional Design Division**

and required increases in aircraft performance—has increased the required number of technical staff, even with the use of advanced design tools (e.g., CAD/CAM systems).

## FACILITIES

Historically, a design organization has had a variety of research, testing, and production facilities associated with it. According to our survey results, these commonly include:

- High- and low-speed wind tunnels.
- Test ranges.
- Research, environmental, and composites labs.
- Fabrication (both development and production) facilities.
- Simulation facilities.
- Test bed aircraft.

The cost of privately owned facilities is reflected in a firm's overhead rate and to a large extent is paid for through overhead charges on production contracts. In some cases, the government owns both test and production facilities that are made available to the industry or specific firms. For instance, the F-16 is produced in a government-owned, contractor-operated facility in Fort Worth, Texas.

Many industry officials believe that it is important that these facilities be closely associated with the core design organization, rather than be external to the organization, to allow tailoring of facilities to specific needs and to increase availability and responsiveness. However, some types of very large, expensive facilities have historically been owned by the government or only a single firm, which then contracts out use of the facilities. Large wind tunnels and test ranges are examples of these. For the purposes of maintaining design capability, it is not clear which structure is most effective. In fact, the declining business base supporting the aircraft industry suggests that an increasing proportion of facilities will be shared in the future, regardless of who owns them.

## FINANCIAL SUPPORT

One of the key insights we sought from this survey was a determination of the minimum size and cost of a design organization needed for it to be fully competitive on future aircraft development programs. This would include both technology base and advanced design functions, as well as some limited capability in critical functional areas: aerodynamics, materials, avionics, special technologies (e.g., low observables), and production engineering. We obtained a 20-year time series of financial data from five design organizations, and in each case, somewhere during that time span the organization experienced a period when it had no major design and development project under way. During those periods, the design/development organization was partly supported by corporate funds, suggesting that the resulting organization was deemed by the corporation to be essential to its long-term business prospects. By tracking the size and composition of the design-relevant portions of the division through those periods, we obtained some indication of how large that "minimum" design organization might be.

Figure 2.5 summarizes that set of survey results. It shows a representative profile of R&D funding and total technical staff over a 20-year period. Figure 2.5 is a composite picture, generated by plotting funding and staff data for the five design organizations in our database and overlaying those plots, shifting each so that the minimum-funding periods corresponded. Thus, the figure is representative of the dominant patterns we observed but does not represent the actual profile of any one of the companies surveyed. Interestingly, there was very little variation in the minimum and maximum sizes of the design organizations we examined; only the timing of the cycle differed. The minimum activity period for each firm varies as a function of the programs it is involved with at a given time, but the actual size of the minimum in terms of personnel and funding base was highly consistent.

There is typically a cycle of activities that starts with the relatively large organization (several thousand people) required for engineering and manufacturing design of a full weapon system. As that project draws to completion, the staff size is reduced, leading to a relatively flat period, followed by a buildup to the next major design activity. For our purposes, the important part of the cycle is the period in which there are no major system design activities under way. This represents the historical minimum size that design organizations reached, characterized by about $100 million in annual funding and 1000 people in engineering and technical management. The activities of this minimum core group include advanced design studies and technology base work. Note that independent research and develop-

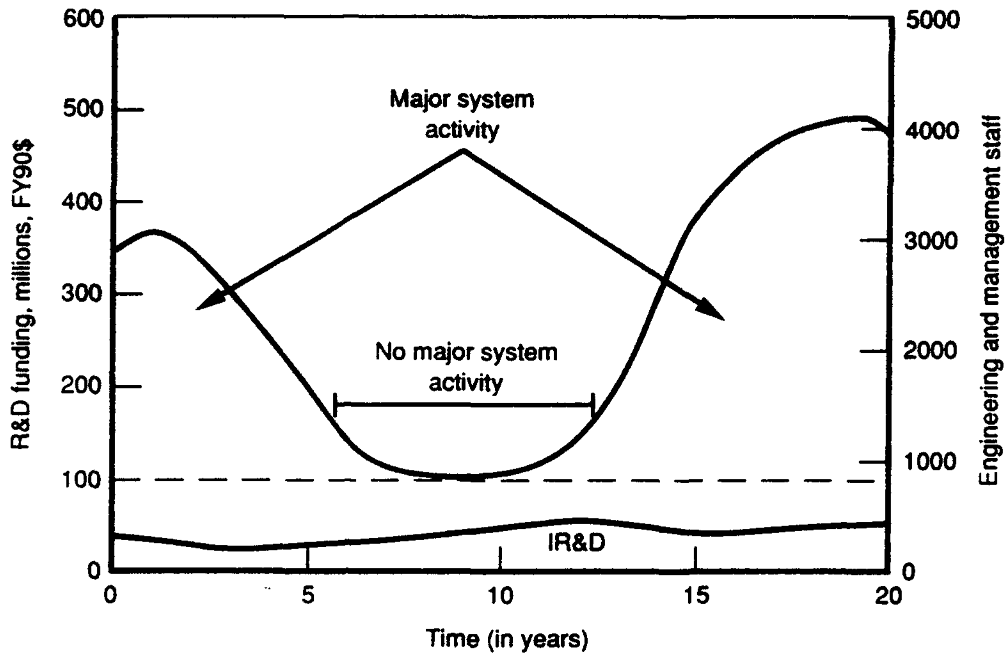



**Figure 2.5—Representative Design Organization Staffing and Funding Profiles**

ment has been an important component of the funding base during periods of no major system activity. Since IR&D is currently reimbursed through overhead allocations on government contracts, and production contracts are generally larger than R&D contracts, there has historically been a substantial production base behind this design organization.

## INSTITUTIONAL STRUCTURE AND MANAGEMENT ORGANIZATIONS

The design capability resources described above—technology base, personnel, facilities, financial support—do not operate in a vacuum. Institutional structures and management organizations are required to tie them together.

Institutional structure refers to the relationships between major organizations involved in aircraft design and development. This includes the technology base actors (government, industry, and academic labs), the aircraft industry (both prime contractors and subtiers), and government program offices and supporting agencies. This infrastructure defines the pathways and mechanisms through which new concepts and technology pass.

Management organizations refer to relationships within each of these organizations. For instance, many aircraft divisions have a matrix organization in which an engineering department can supply skilled personnel to specific programs at the time that their particular expertise is required. A similar relationship exists between the Aeronautical Systems Division and System Program Offices.

These institutional and managerial relationships have evolved over time as required by changes in the design process and the acquisition and business environment. Future changes in both environment and process are likely to require appropriate restructuring.

## SUMMARY

To summarize, maintaining design capability requires both a sufficient number of design organizations and an adequate experience base for each of those organizations. Those design organizations have historically required a minimum of about $100 million in research and technology funding; about 1000 technical staff, including scientists, technologists, design engineers, and production engineers; and a wide range of facilities including labs, wind tunnels, radar ranges, and production. Funding and staff for major system activities are additive.

Also necessary for successful development of advanced systems is a sustained program of research and advanced development work on many of the underlying technologies. Some of those technologies, as illustrated by the above discussion of composite materials, require decades of concerted effort before they are brought to the point where they can be confidently incorporated into weapon system designs. The aircraft firms and major suppliers play key roles in focusing and sustaining such technology development work, frequently employing corporate funds as well as government funds.

The government and industry institutions involved in military aircraft design and development and design capability resources have been shaped by characteristics of the acquisition environment. Many of these characteristics—development and production budgets, system costs, number of development and production programs, industry size and structure, and broad acquisition policy—have important effects on design capability. Factors and trends potentially affecting the quantity or quality of design capability resources are discussed in the next section.

# 3. FACTORS AND TRENDS AFFECTING DESIGN CAPABILITY

As the size and composition of U.S. military forces evolve, and as the associated budgets retreat from the peaks of the mid-1980s, the business of developing and producing military aircraft will undergo some major changes. In this section, we outline some of the major trends that are apparent and make some rough forecasts of the likely environment for military aircraft development and production throughout this decade. In Section 4, we offer some estimates of how these trends might affect the industry's ability to maintain a strong design and development posture in the near term.

We examine four trends that seem particularly important in terms of affecting design capability and industry structure and health:[1]

- Combat aircraft are becoming more complex and expensive.
- Budgets are continuing to decrease and will probably not stabilize for several years.
- The frequency of new projects has decreased, for both production and development.
- Industry size and composition have not changed very much, but the structure of the business base is changing.

## AIRCRAFT COSTS

The trends of increasing development and production costs for military aircraft are long-standing and well documented. With an occasional exception such as the F-16, each succeeding design in any particular series of models/types (fighters, bombers, attack aircraft, etc.) has cost more than the preceding design. One estimate shows that the inflation-adjusted unit procurement cost of tactical aircraft has increased, on average, about 11 percent per year since 1963 (see Table 3.1).[2] While the database for bombers is much smaller, the same

[1]We examined other trends, such as smaller total production quantities and longer production runs at lower rates, but these appear to be less important. The industry appears to be largely indifferent to producing a few aircraft at high cost versus producing many aircraft at low cost.

[2]Based on change from A-7E to F-14D.

**Table 3.1**

**Trends in Aircraft Development and Procurement Costs (millions, FY91$)**

| Program | R&D Start | RDT&E | Unit Procurement |
|---|---|---|---|
| A-7E | 1963 | 135 | 9 |
| A6-E | 1969 | 1146 | 28 |
| A-10 | 1973 | 1199 | 10 |
| AV-8B | 1976 | 2049 | 27 |
| F-100 | 1952 | 127 | |
| F-104 | 1954 | 118 | |
| F-111A/B/C/D/E | 1969 | 6791 | 55 |
| F-14A/B | 1969 | 5287 | 52 |
| F-15A/B/C/D/E | 1970 | 8227 | 31 |
| F-16A/B/C/D | 1975 | 3302 | 17 |
| F/A-18A/B/C/D | 1978 | 7434 | 35 |
| F-14D | 1984 | 1992 | 84 |
| ATF/F-22 | 1991 | 15,082 | 66 |
| E2-C | 1968 | 655 | 49 |
| EA-6B | 1970 | 442 | 51 |
| E3-A | 1970 | 4351 | 142 |
| E-6A | 1981 | 452 | 116 |
| P-3C | 1965 | 73 | 50 |
| P-7A | 1987 | 894 | 49 |
| T-45TS | 1975 | 696 | 17 |
| T-465A | 1982 | 547 | 9 |
| B-1A | 1970 | 9154 | 131 |
| B-1B | 1982 | 4504 | 285 |
| C-5B | 1982 | 0 | 162 |
| C-17 | 1985 | 5836 | 181 |

NOTES: RDT&E is research, development, test, and evaluation. Dates for F-100, F-104, EA-6B, and C-5B are production start. B-1A, T-46A, and P-7A were canceled prior to any production. No development costs were given for the C-5B in the December 1988 SAR. USAF Raw Inflation Indices from AFR 173-13 were used to derive constant dollars. F-100 and F-104 data from Air Force Systems Command, *Affordable Acquisition Approach Study*. Data on other aircraft from most recent *Selected Acquisition Reports*.

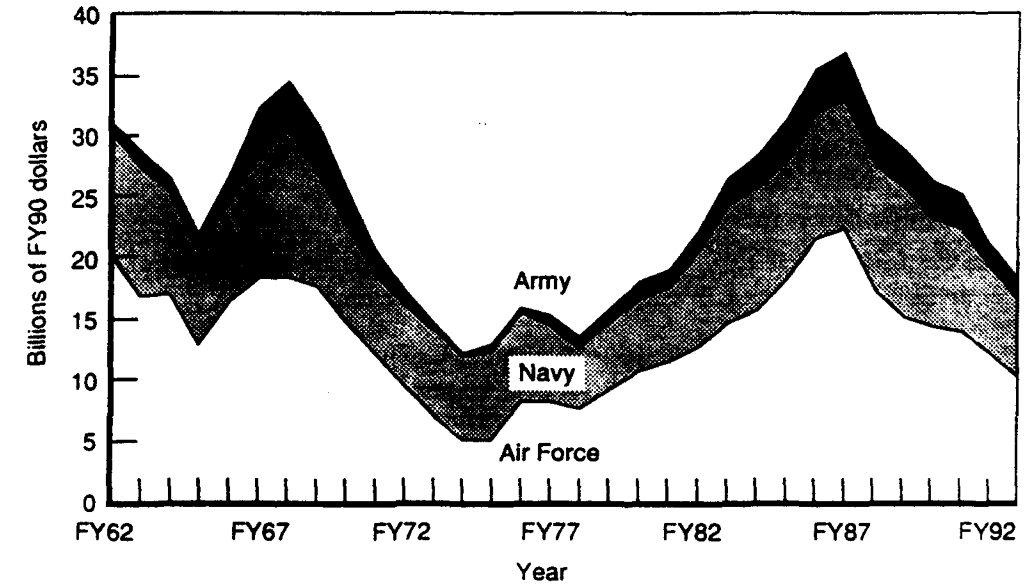
trends obviously apply: The B-1B costs several times as much as the B-52, and the B-2 is expected to cost at least twice as much as the B-1B. These trends are consistent with those of other kinds of military equipment and reflect the continuing drive to be competitive with performance levels of opposing systems.

The same trends are apparent in development cost, as shown in Table 3.1. The development of the F-22 is expected to cost roughly one hundred times more than its predecessors 40 years ago. To a large extent, increasing costs are a result of the increasing complexity and performance of military aircraft. Incorporation of low-observable technology and increased avionics components are examples of this.

## AIRCRAFT BUDGETS

After real dollar increases that spanned FY78–FY87, military aircraft outlays, are on the decline. Figure 3.1 shows real-dollar military aircraft procurement outlays by service over the last 30 years, including DoD budget projections through 1993. These values include funding for both fixed-wing planes and helicopters.

Air Force spending currently accounts for about 60 percent of these outlays, while the Navy comprises approximately 30 percent. Total outlays peaked in FY87 at $37 billion (constant 1990 dollars), surpassing even the FY68 high of $35 billion during the Vietnam War. Aircraft procurement outlays in FY91 totaled $25 billion, a value expected to decline to $18 billion by FY93. While the FY93 value is low relative to the levels of the mid-1980s, it is larger than the minimum




SOURCES: *Aerospace Facts & Figures 1990–1991* (Washington, D.C.: Aerospace Industries Association, 1990, p.46). FY91–FY93 values from *Budget of the U.S. Government, FY92* (Washington, D.C.: General Printing Office, 1991).

**Figure 3.1—Outlays for U.S. Aircraft Procurement**

levels of outlays experienced in the post-Vietnam era—$12 billion in FY74 and $13 billion in FY78.

Projections of future budgets, together with the need to modernize the force structure of both the Air Force and Navy in certain categories of aircraft, suggest that at least a few production lines will continue to be active. Most current projections suggest that overall fixed-wing aircraft procurement (all types, both Air Force and Navy) will be about $10 billion per year for the remainder of this decade. That estimate assumes continued production of the C-17 and the F/A-18, together with at least some early production of the F-22. Thus, we observe that while aircraft procurement budgets have decreased significantly from their FY87 peak, they are likely to remain sufficient to keep several production lines open at any given time, thus supporting several firms.

Trends in research, development, test, and evaluation (RDT&E) funding have been somewhat more stable than trends in procurement funding and are projected to remain so throughout the decade.[3] Except for a dip in the mid-1970s, total funding for the aeronautical technology base (budget categories 6.1, 6.2, and 6.3a) has been at a level of roughly $1 billion per year for the past two decades. That level of support seems likely to be sustained for the remainder of this decade. Program-specific RDT&E funding for current development efforts (F-22, AX, F/A-18 upgrade) will likely add several billion dollars per year.

## NUMBER AND FREQUENCY OF PROGRAMS

The combination of increasing unit cost and constant, or decreasing, budgets has inevitably led to a sharp reduction in the number of active projects, in both development and production.

One important trend is a dramatic decrease in the number of active military aircraft production lines. As Figure 3.2 shows, the number of active production lines for both Air Force and Navy fixed-wing aircraft has decreased steadily over the past several decades, due in part

[3]In the new acquisition environment, DoD policy is to emphasize R&D over production. For instance, see Office of the Secretary of Defense White Paper, *A Revised Approach to Defense Acquisition*, 4 March 1992.

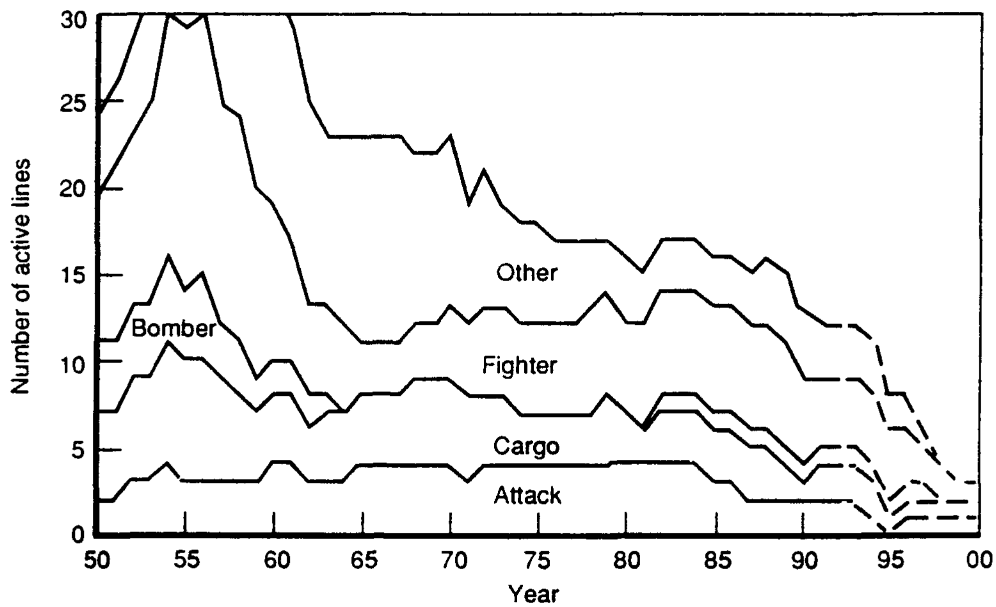



**Figure 3.2—Number of Active Military Aircraft Production Lines**

to decreases in procurement budgets, increases in aircraft system costs, and longer useful lifetimes of aircraft. That trend is likely to continue. In 1991, there were 12 active production lines; by the end of this decade, there will be far fewer, possibly as few as 3 (those might be the F/A-18, F-22, and the C-17).

Another view of industry activity trends is shown in Figure 3.3, where each of the horizontal bars represents the production period of one aircraft model (e.g., all F-4 aircraft represent one line on the graph). The envelope represented by the left-hand side of the bars shows the rate of new model introduction and is thus a rough proxy for the rate of new design activity, which has clearly been declining.

To gain a more thorough perspective on the rate of new design activity, we counted the number of new designs that were brought to flight status each year since 1950. In this listing, we included:

- Only designs where at least one flight was achieved.
- All fixed-wing designs sponsored by the Department of Defense, including prototypes and experimental models.
- Only "new" designs; that is, we excluded modifications and subsequent series following a new design (e.g., we include the F-4A but

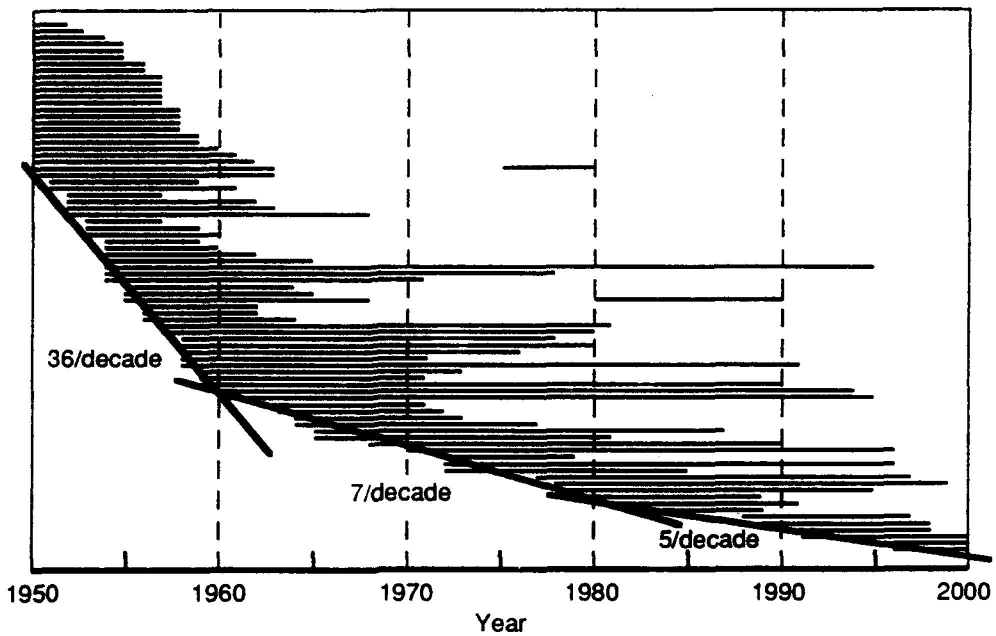



**Figure 3.3—U.S. Military Aircraft Production Time Spans**

not the F-4B, F-4C, etc.), and we excluded designs that were military modifications of commercial designs.[4]

The results are shown in Table 3.2. Interestingly, it is apparent that more new designs reached flight status in the 1950s than in all of the subsequent four decades combined.

The same information is displayed in Figure 3.4, where the frequency of new aircraft designs is summarized by decade. The figure shows a steady reduction in the level of new design activity. In the 1950s, 49 new fixed-wing aircraft were flown; 4 new designs have flown in the 1990s, and expectations are for perhaps 1 or 2 more by the turn of the century.

## THE CHANGING SIZE AND STRUCTURE OF THE AIRCRAFT INDUSTRY

Industry observers have asserted that a number of economic and financial indicators suggest that military aircraft prime contractors

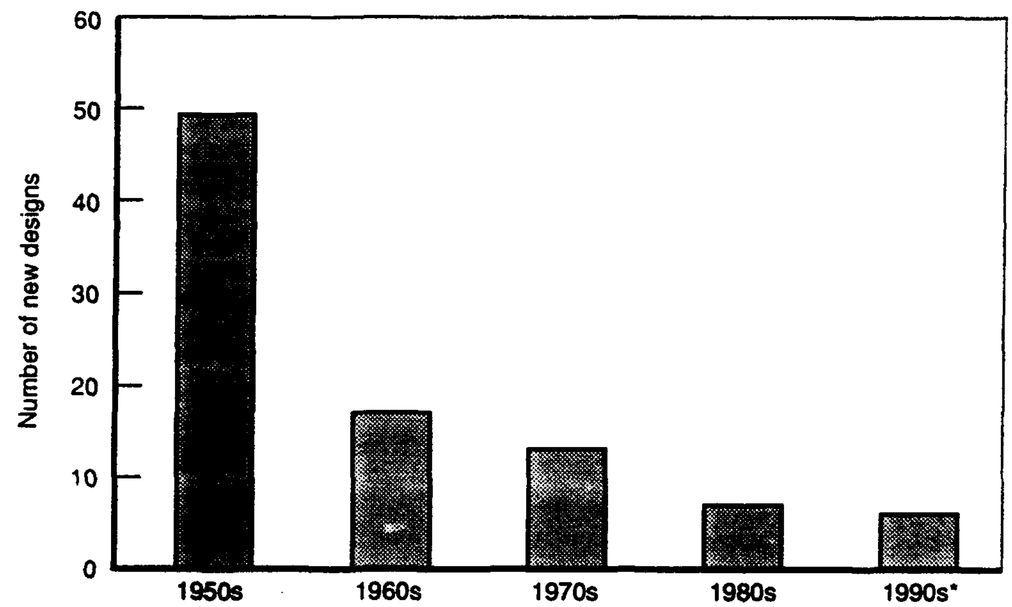
[4]This inevitably led to some subjective choices, but those were not frequent enough to seriously affect the overall structure of the data set.

## Table 3.2

## New Military Aircraft Designs

| Model | First Flight Company | Model | First Flight Company |
|---|---|---|---|
| XP5Y-1 | 4 - 50 Convair | A-6 | 4 - 60 Grumman |
| A2D | 6 - 50 Douglas | E-2/C-2 | 10 - 60 Grumman |
| XC-120 | 8 - 50 Fairchild E&A | SR-71/A-12 | 4 - 62 Lockheed |
| F4D | 1 - 51 Douglas | XV-4A | 7 - 62 Lockheed |
| X-5 | 6 - 51 Bell | X-21 | 4 - 63 Northrop |
| F3H | 8 - 51 McDonnell | X-19 | 11 - 63 Curtis |
| X-2 | 3 - 52 Bell | C-141 | 12 - 63 Lockheed |
| B-60 | 4 - 52 Convair | XC-142 | 8 - 64 LTV |
| F10F | 5 - 52 Grumman | B-70 | 9 - 64 NAA |
| X-3 | 10 - 52 Douglas | F-111, FB-111 | 12 - 64 GD |
| A3D | 10 - 52 Douglas | F-111B | 5 - 65 Grumman |
| B-52 | 10 - 52 Boeing | OV-10 | 7 - 65 NAA |
| S2F/TF-1/WF-2 | 12 - 52 Grumman | A-7 | 9 - 65 LTV |
| F2Y-1 | 4 - 53 Convair | X-22 | 3 - 66 Bell |
| F-100 | 5 - 53 NAA | X-26B | 7 - 67 Lockheed |
| B-57 | 7 - 53 Martin | C-5A | 6 - 68 Lockheed |
| F-102 | 10 - 53 Convair | X-24 | 4 - 69 Martin |
| F-104 | 2 - 54 Lockheed | F-14 | 12 - 70 Grumman |
| R3Y-1/2 | 2 - 54 Convair | S-3 | 1 - 72 Lockheed |
| B-66 | 6 - 54 Douglas | A-10 | 5 - 72 Fairchild-Republic |
| XFV-1 | 6 - 54 Lockheed | YA-9 | 5 - 72 Northrop |
| A4D | 6 - 54 Douglas | F-15 | 7 - 72 MDAC |
| F11F | 7 - 54 Grumman | F-16 | 1 - 74 GD |
| XFY-1 | 8 - 54 Convair VTOL | YF-17 | 6 - 74 Northrop |
| C-130 | 8 - 54 Lockheed | B-1A/B | 12 - 74 NAA |
| F-101 | 9 - 54 McDonnell | YC-15 | 8 - 75 MDAC |
| T-37/A-37 | 10 - 54 Cessna | YC-14 | 8 - 76 Boeing |
| F8U3 | 3 - 55 LTV | XV-15 | 5 - 77 Bell |
| P6M-1 | 7 - 55 Martin | F/A-18 | 11 - 78 MDAC |
| U-2 | 8 - 55 Lockheed | AV-8B | 11 - 78 MDAC |
| XV-3 | 9 - 55 Bell VTOL | F-117 | 6 - 81 Lockheed |
| F-105 | 10 - 55 Republic | F-20 | 8 - 82 Northrop |
| X-13 | 12 - 55 Ryan VTOL | X-29 | 12 - 84 Grumman |
| C-133 | 4 - 56 Douglas | T-46 | 10 - 85 Fairchild-Republic |
| F5D | 4 - 56 Douglas | T-45 | 4 - 88 MDAC |
| F-107 | 9 - 56 NAA | V-22 | 3 - 89 Bell/Boeing |
| B-58 | 11 - 56 Convair | B-2 | 7 - 89 Northrop |
| F-106 | 12 - 56 Convair | YF-23 | 8 - 90 Northrop/MDAC |
| X-14 | 2 - 57 Bell VTOL | YF-22 | 9 - 90 Lockheed/GD/Boeing |
| C-140 | 9 - 57 Lockheed | X-31 | 10 - 90 NAA/MBB |
| T-2 | 1 - 58 NAA | C-17 | 6 - 91 MDAC |
| F-4 | 5 - 58 McDonnell | | |
| A3J/A-5 | 8 - 58 NAA | | |
| T-39 | 9 - 58 NAA | | |
| T-38 | 1 - 59 Northrop | | |
| AO-1/OV-1 | 4 - 59 Grumman | | |
| X-15 | 6 - 59 NAA | | |
| F-5A/B/E/F | 7 - 59 Northrop | | |
| X-18 | 11 - 59 Hiller | | |

NOTES: VTOL = Vertical Take-Off and Landing; GD = General Dynamics; MDAC = McDonnell Douglas; MBB = Messerschmitt-Bolkow-Blohm.




*1990s includes YF-22, YF-23, C-17, X-31, AX, and X-30 NASP.

**Figure 3.4—Number of New Military Aircraft Designs**

have been experiencing a decline in financial health since the mid-1980s. We review several metrics here—military aircraft revenues, rates of return, indebtedness, and other financial measures. These measures suggest that while there is pressure for consolidation, the smaller military aircraft business base seems adequate to support several of the present firms, albeit at a somewhat smaller size than it did during the past decade. In fact, many of the financial indicators we examined have decreased only with respect to a mid-1980s peak, not with respect to historical averages. However, these changes could have a relatively large effect on corporate support for design teams and broad technology development programs.

As the predominant buyer of defense equipment (some is exported), DoD is involved in the structure of the military aircraft industry. Its decisions on what systems to buy determine which companies remain in business, their areas of technological expertise, and ultimately their size and financial health. For example, the Navy's decision to exclude funding for the F-14D remanufacturing program from its FY92 budget request necessarily affects the financial viability of Grumman. The recent decision to terminate the B-2 after a maximum of 20 production aircraft will certainly affect Northrop's sales and revenues.

Historically, profits from production contracts have provided the key incentive for firms to remain in the military aircraft industry. These profits have also been the source of private investment funds for work on each new generation of aircraft programs. The dollar volume of a firm's production contracts is also the basis upon which a reimbursement rate is set for IR&D projects.[5] But if military aircraft acquisition trends continue—smaller production runs and declining budgets—the volume of profits to be earned from production contracts will decline.

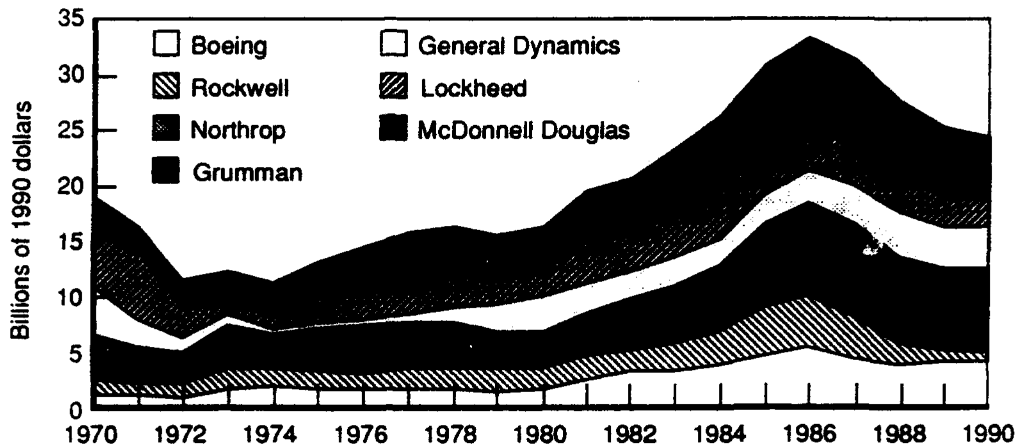
### Sales Volume and Product Mix

Figure 3.5 shows the estimated value of military aircraft sales for the seven companies that were prime contractors on military planes during the 1980s: Boeing, General Dynamics, Grumman, Lockheed, McDonnell Douglas, Northrop, and Rockwell. This figure includes revenues from government contracts funded out of DoD's aircraft procurement and RDT&E budgets. It also includes the value of military aircraft exports.

Military aircraft revenues peaked in calendar year 1986 (CY86) at over $33 billion (in constant 1990 dollars). By CY90, these sales had dropped 27 percent to just over $24 billion. While this is a significant decline, the value of sales has not yet approached the $11 billion minimum these companies experienced during CY72–CY74. The 1990 shares of these aggregate military aircraft sales are as follows: Boeing, 17 percent; Rockwell, 4 percent; Northrop, 17 percent; Grumman, 14 percent; General Dynamics, 15 percent; Lockheed, 10 percent; and McDonnell Douglas, 24 percent. These shares have not changed much since CY70, with a few notable exceptions: Boeing's percentage grew substantially during the 1980s, Lockheed's share dropped dramatically in the early 1970s, and Rockwell has had relatively small military aircraft revenues since it completed the B-1B program in the late 1980s.

Figure 3.6 shows the aggregated sales of the seven prime contractors by general category of products. Total sales (in 1990 dollars) have grown substantially over the period, from $46 billion in CY76 to $86 billion in CY90. Military aircraft sales generally comprised the

[5]For a description and analysis of the IR&D program, see Arthur Alexander, Paul Hill, and Susan Bodily, *The Defense Department's Support of Industry's Independent Research and Development (IR&D): Analyses and Evaluation*, RAND, R-3649-ACQ, April 1989.

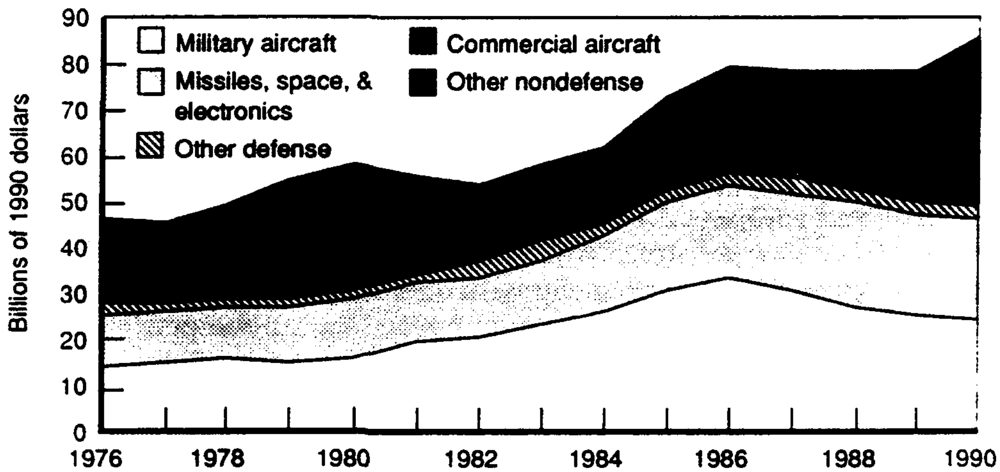



SOURCE: Estimated from segment data taken from the annual reports of each firm. Some estimates, such as those for Grumman, Northrop, and Rockwell, overstate the actual value because of lack of data on commercial aircraft subcontracts conducted by military aircraft segments. The estimate for McDonnell Douglas actually understates its military aircraft sales because it excludes the value of military transport contracts such as the C-17 program.

**Figure 3.5—Approximate Military Aircraft Sales of Seven Prime Contractors**

largest portion of total sales; increased military aircraft sales were the major driver behind increased total sales in the early 1980s. Missiles, space, and electronics equipment were frequently the second largest segment, with sales ranging from $11 billion in CY76 to $22 billion in CY90. Other defense production—nonaerospace production such as shipbuilding and land armaments—was a fairly constant $2 billion to $3 billion in sales. Commercial aircraft revenues were at their minimum ($9 billion) in CY82 but grew to $28 billion by CY90, surpassing both military aircraft and missiles, space, and electronics. Commercial aircraft account for most of the recent growth in total sales. Nondefense production other than commercial aircraft decreased in value during the mid-1980s—in CY76 it accounted for $10 billion in sales, then it fell to a low of $6 billion in CY83—but had recovered to $9 billion in CY90.

With the exception of the mid-1980s, military aircraft revenues relative to other types of sales have not changed substantially over the period 1976–1990. Military aircraft sales averaged 35 percent of total sales over this period and were as large as 42 percent over




SOURCE: Estimated from segment data taken from the annual reports of each firm. These values are not exact since, for example, some commercial aircraft subcontracts are performed by military aircraft segments and are counted as military aircraft revenues. *Commercial aircraft* includes passenger jets and light aircraft. *Other defense* includes production of land armaments (such as tanks), ships, submarines, etc. *Other nondefense* includes all nonmilitary production other than commercial aircraft such as Rockwell automotive equipment, GD's mining materials, Boeing's agribusiness, etc.

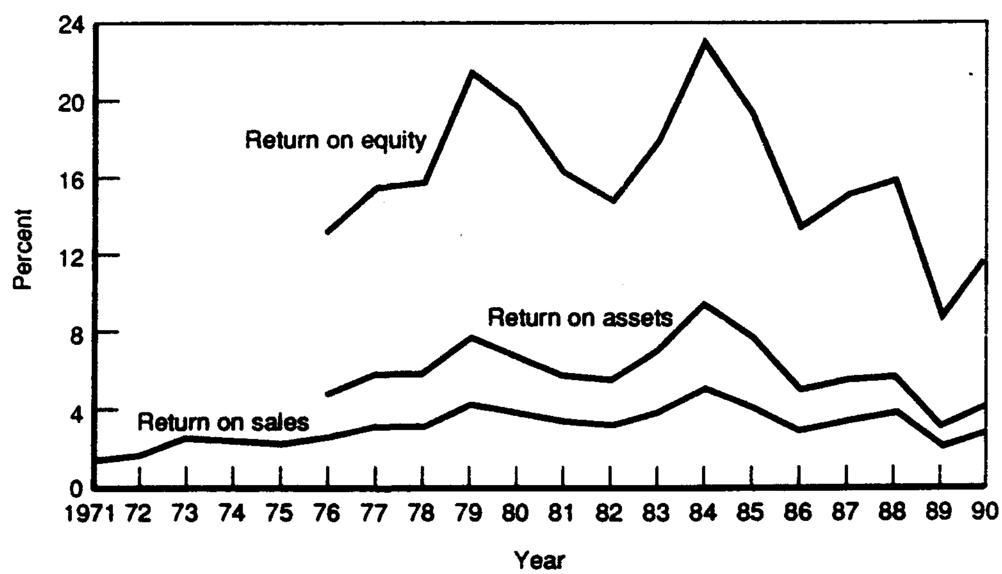
**Figure 3.6—Aggregate Sales of Military Aircraft Prime Contractors by Segment**

CY84–CY86. This trend is now reversing, however: By CY90, the percentage fell back to 28 percent. Total nondefense sales—commercial aircraft and other nonmilitary revenue—comprised the largest percentage of aggregate sales until CY81. Military aircraft sales then dominated over the period CY82–CY88, only to be replaced once again by nondefense revenues in CY89. Other defense production—including missiles, space, electronics, and other military commodities—accounted for about one-fourth of total sales through CY81 and then rose to approximately one-third of the total. The missiles, space, and defense electronics segments appear to be the one growth area in defense procurement, and the aggregate sales of these prime contractors reflect this trend.

## Profitability and Debt

The demise of the Cold War and subsequent decreases in DoD's military spending have decreased the profitability of most defense contractors relative to the mid-1980s but not relative to historical averages. Figure 3.7 shows weighted average rates of return for the seven aircraft prime contractors. All three metrics (returns on sales [ROS], assets [ROA], and equity [ROE]) capture information about profitability, but they are presented jointly since any individual measure could be misconstrued. For example, if a firm uses a large amount of physical plant and equipment provided by the government, the value of assets that it owns privately will appear low and its ROA high. But when we consider the efficiency with which a company converts its sales into profits, the same firm might resemble its competitors more closely. Note that these measures are based on consolidated values; therefore, they also reflect information about the profitability of segments other than military aircraft.

What is surprising from Figure 3.7 is that these measures of profitability have actually been falling since CY82–CY84, several years prior to both the peak in DoD's total procurement budget and that for aircraft outlays. Average ROS reached 5.0 percent in CY84, dropped to 2.2 percent by 1989, and was about 2.7 percent in CY90. Likewise,



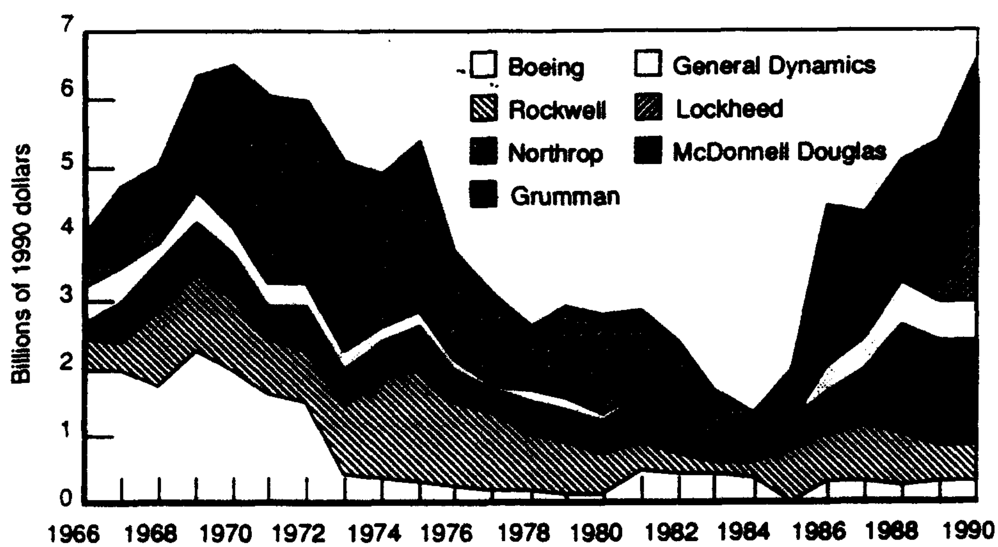

NOTE: To compute an average, each corporation's consolidated rate of return was weighted by its share of the total military aircraft sales, assets, and equity for the seven firms. ROS, ROA, and ROE are computed as net income as a percentage of operating revenues, total assets, and common shareholder equity, respectively.

**Figure 3.7—Rates of Return for the Military Aircraft Industry**

average ROA peaked in CY84 at 9.3 percent, fell as low as 3.1 percent in CY89, then rose to 4.1 percent in CY90. Peak ROE was 23.0 percent in CY84, fell to 8.8 percent in CY89, and then rebounded to 11.8 percent in CY90. The data for 1990, and preliminary figures for 1991, indicate that profitability has improved now that firms have begun shedding excess staff and capacity.

Changes in defense contracting policies and the willingness of defense firms to maintain a sizable volume of production capacity resulted in larger amounts of private borrowing at the end of the 1980s. Figure 3.8 shows the value of long-term debt—notes and other types of obligations due after one year—for the seven aircraft prime contractors. There are two important caveats to consider regarding these debt data. First, this figure does not include the long-term debt of financial subsidiaries because a comparable time series of data was unavailable. A more accurate depiction of the value of outstanding debt should include that of financial subsidiaries. Second, debt values prior to CY77 do not include the value of long-term leases, which are now considered equivalent to other types of debt. Consequently, values prior to that year are understated.

Aggregate long-term debt for the seven firms reached a high of $6.5 billion in CY70, fell to a low of $1.3 billion in CY84, but returned to




SOURCE: Corporate annual reports. Values do not include the long-term debt of financial subsidiaries.

**Figure 3.8—Long-Term Debt of Military Aircraft Prime Contractors**

its previous high of $6.5 billion in CY90. To get an idea of the magnitude of additional long-term debt held by the financial subsidiaries of these corporations, in CY82 it was approximately $1.2 billion, and it totaled about $2.3 billion in CY90.[6] Therefore, total long-term debt in CY90 was $8.8 billion. Short-term debt obligations due within one year accounted for an additional $3.1 billion in CY90. In recent years, McDonnell Douglas, General Dynamics, Northrop, Lockheed, and Grumman have all accumulated large amounts of debt, increasing their debt-to-equity ratios significantly. It should be noted that the cost of debt servicing has different implications for financial viability than does total debt. Debt servicing requires adequate cash flow, while total debt relates to long-term investment and capital requirements.

Industry representatives have argued that aircraft procurement outlays, military aircraft sales, profitability measures, and levels of indebtedness all suggest that the military aircraft industry has experienced declining financial health since the mid-1980s. Additionally, they assert that a number of acquisition policy changes over the last decade have contributed to this decline—for example, lower profit markups within the weighted guidelines, the phaseout of Completed Contracting Method (CCM) tax laws, lower progress payment rates, an increased reliance on private financing of special tooling, lower IR&D/Bid and Proposal (B&P) recovery rates, and the use of fixed-price development contracts.[7] Our analysis does not fully support these arguments. Though we do not discount the views of the industry, we observe that any recent "decline" in financial health is only measurable from a mid-1980s peak that was considerably higher than historical averages.

### Number of Aircraft Prime Contractors

Despite these fluctuations in financial posture, the size of the industry, measured in the number of firms acting as prime contractors on military aircraft programs, has not changed very rapidly. Figure 3.9 shows the number of parent corporations and the total number of air-

[6]Estimates derived from the financial notes accompanying balance sheets within corporate annual reports.

[7]*The Impact on Defense Industrial Capability of Changes in Procurement and Tax Policy, 1984–1987*, a study conducted by the MAC Group for the Aerospace Industries Association, February 1988. See also, Anthony Velocci, Jr., "U.S. Defense Industry Must Change Ways to Stay Out of Financial Emergency Room," *Aviation Week & Space Technology*, 24 December 1990, pp. 16–17.

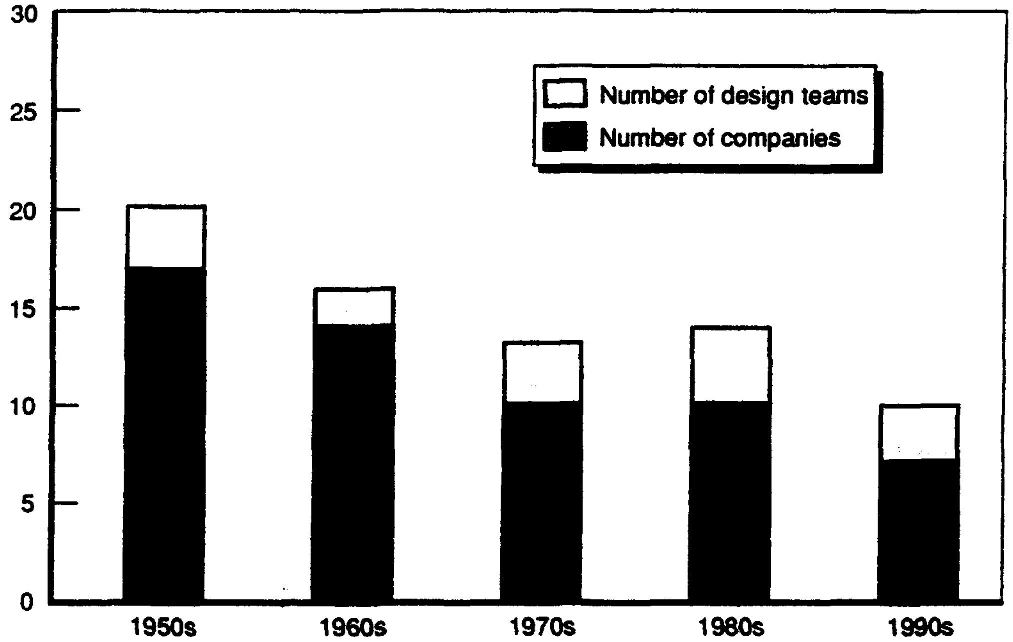



**Figure 3.9—Number of Design Organizations (1950–1990)**

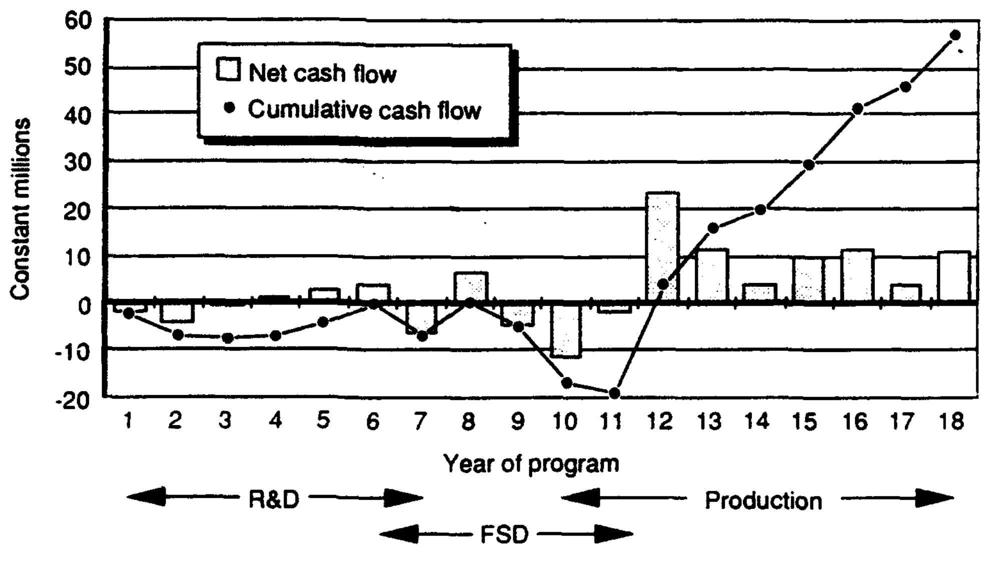
craft division-level organizations active in each decade during the second half of the century. As we begin the 1990s, only Fairchild-Republic and LTV have exited the industry. Fairchild-Republic left the aircraft industry altogether, while LTV became an important subcontractor on several recent aircraft programs.

## R&D Investments

Declining defense budgets have resulted in fierce competition among contractors, leading to an increased reliance by DoD on private corporate investments for weapon system design work.

The current method of designing and producing advanced technology weapon systems uses a series of contracts that proceeds from initial concept development through engineering and manufacturing development (EMD), production, deployment, modification, and field support. There have been many variations on how this process has been implemented over the years, but generally, firms compete most heavily at the earlier stages of development, often investing their own funds toward R&D. Rivalry is less fierce once the acquisition has reached the EMD and production phases, but it is at these later points in the development cycle that firms have typically been required to accept more of the burden for cost overruns on their contracts. Firms tend to earn a majority of their profits at the final phases of the production cycle. The reason is twofold: First, technical risks are lower, and second, the dollar value of production contracts is relatively large and the volume of production profits is roughly proportional to it.

The life cycle of military aircraft is far different from the development and manufacture of most commodities. It can take eight to ten years to advance a program through the stages of engineering and manufacturing development and initial production, and often the break-even point for a contractor is equally long. Figure 3.10 presents a hypothetical example of a $1 billion military aircraft program that uses a series of three contracts over a period of 18 years. Although this example is hypothetical, it is based upon the life cycles of actual defense contracts surveyed for an industry-financed study of the impact of procurement policies.[8] Annual net cash flows—contract payments less incurred costs—are shown in the shaded bars, while cumulative cash flow is depicted by the line. Notice that there are some positive net cash flow values in years 4 through 6, which would




NOTE: FSD = Full-scale development.

**Figure 3.10—Cash Flow of a Hypothetical Military Aircraft Program**

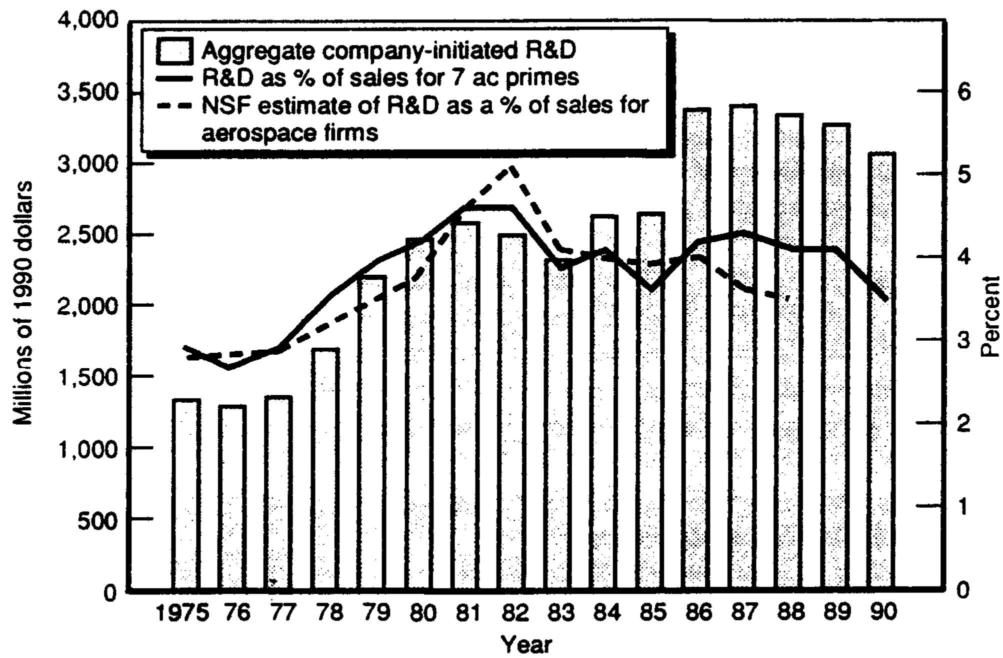
[8] *The Impact on Defense Industrial Capability of Changes in Procurement and Tax Policy, 1984-1987.* Note that a "$1 billion" aircraft program is at least one order of magnitude less than current programs.

be most likely to happen if a company worked under a cost-plus R&D contract. In this example, the contractor did not break even and begin to earn sizable profits until 12 years after the project was initiated. Once the project reached its production stage, however, profits (as measured by net cash flow) grew substantially. This pattern demonstrates an implicit working agreement that has been in effect for years: Military services expect corporations to invest private funds in the design and development stages of a weapon system in return for profits on production contracts. Presumably, defense firms have weighed the net present value of expected profits from production contracts against up-front private investments when deciding whether to bid on design work. However, other factors would also affect the decision to bid on a new program, including specific contracting strategies and whether it is the only new aircraft program in the foreseeable future.

Evidence of an increased reliance on corporate investments can be found in the level of privately financed R&D spending. Figure 3.11 shows the sum of company-sponsored R&D for the seven military aircraft contractors. It includes the value of R&D spending that was either financed privately with corporate funds or through the DoD IR&D/B&P reimbursement program. We refer to these values as "company-sponsored" because the companies themselves had control over the size, scope, and nature of research. The totals exclude direct contracts for R&D work.. It is important to note that these values include all corporate R&D spending (military and nonmilitary, aircraft and nonaircraft programs) since less aggregated data were unavailable.

In constant 1990 dollars, the aggregate value of company-sponsored R&D grew from approximately $1.35 billion in the mid-1970s to around $3 billion at the end of the 1980s. Particularly noticeable is a $500 million jump in annual expenditures after CY85. These values include IR&D/B&P expenses that were later reimbursed by DoD, so while they were initially financed with corporate funds, some of that was later recovered. The data suggest that company-sponsored R&D funding has actually increased since the mid-1970s. Corporations generally include the value of development expenses in excess of contract ceiling prices in their R&D totals. So, for example, development costs for the YF-22/YF-23 programs beyond the prototype contract would be considered corporate R&D.

Additionally, Figure 3.11 shows two estimates of company-sponsored R&D spending as a percentage of net sales. R&D spending by the

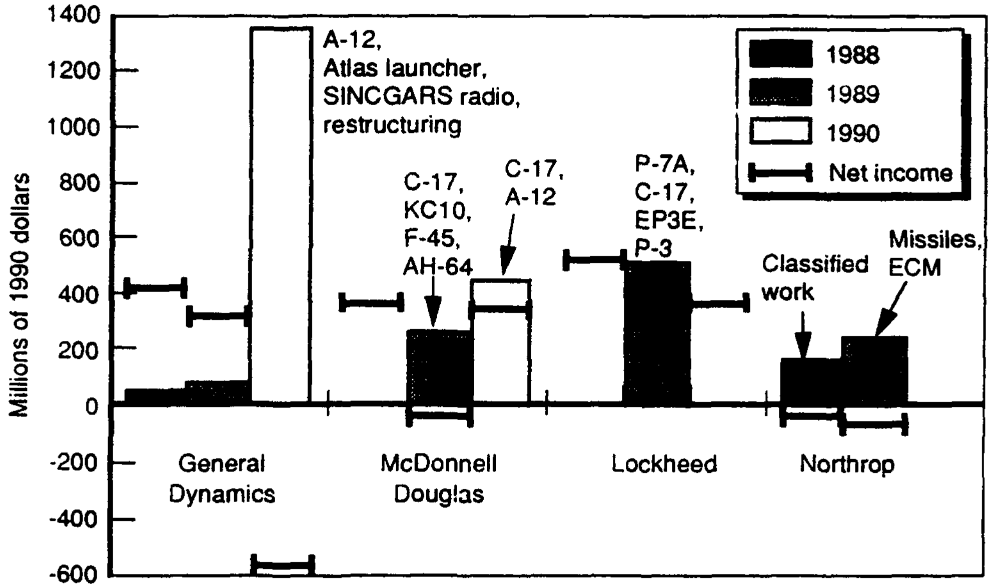



SOURCES: Corporate annual reports and NSF 90-316, April 1990.

**Figure 3.11—Corporate-Initiated R&D Spending**

seven military aircraft prime contractors rose from an average of 2.9 percent in CY75 to a high of 4.6 percent in CY86 and then declined to 3.5 percent in CY90. Such increases in corporate R&D spending were funded, at least in part, through large increases in sales and revenues (see Figures 3.5 and 3.6). For the prime contractors, R&D as a percentage of sales was fairly stable throughout the 1980s, although it did decline slightly in CY83 and CY85. Estimates by the National Science Foundation (NSF) for R&D spending as a percentage of sales among all aerospace firms show an increase from less than 3 percent in CY75 to more than 5 percent in CY82. However, the NSF estimates show a decline during the 1980s to 3.5 percent in CY88. The NSF values were estimated for all corporations whose primary output is either aircraft, aircraft engines and other parts, guided missiles, space vehicles, or space propulsion units and parts.

DoD's use of fixed-price contracts for development work during the 1980s put more of the burden for R&D program overruns in private hands. Figure 3.12 shows write-offs, or declarations of program losses, for four of the seven prime military aircraft contractors over the period 1988–1990. The value of each company's after-tax net in-




SOURCE: Philip Finnegan, "Write-Offs Top $2 Billion in 1990 for Defense Industry," *Defense News*, 18 February 1991, pp. 4, 44. Net income figures are from corporate annual reports.

**Figure 3.12—Recent Corporate Write-Offs**

come for each corresponding year is also provided. Of General Dynamic's $1.36 billion in 1990 write-offs, $724 million was associated with losses on the A-12 program, a fixed-price development contract with the Navy.[9] Similarly, McDonnell Douglas had $350 million in A-12 and $93 million in C-17 write-offs during 1990, with an additional $72 million related to the C-17 in 1989. Both projects used fixed-price development contracts. Lockheed took $503 million in 1989 write-offs, all for military aircraft programs: $300 million on the P-7A; $165 million on the C-17 and E-P3E; and $27 million on P-3 modification work. Northrop took a total of $390 million in write-offs over 1988–1989, but they were related to missiles and defense electronics programs.

Corporate R&D spending, the recent value of corporate program losses on fixed-price development contracts, and formal cost-sharing arrangements for development work like that on ATF prototypes suggest that DoD has relied more heavily on private investments for mil-

[9]Philip Finnegan, "Write-offs Top $2 Billion in 1990 for Defense Industry," *Defense News*, 18 February 1991, p. 4.

itary aircraft programs in recent years. Presumably, the strong degree of rivalry among the seven aircraft prime contractors led to the acceptance of these practices by industry. But the firms may not be in a strong enough financial position to continue this magnitude of investments in the future. Furthermore, several industry officials have stated publicly that they will no longer accept these practices—particularly the use of fixed-price development contracts. Military aircraft prime contractors could conceivably be persuaded to continue accepting fixed-price R&D contracts if it is their only means of winning new programs. However, DoD's more recent strategy of using cost-plus contracts on riskier development work better suits its long-term interest of maintaining a number of competitive design teams.

## SUMMARY OF TRENDS AFFECTING DESIGN CAPABILITY

In this section, we have examined several trends in the acquisition environment that can affect design capability:

- Military aircraft of all types are increasing in cost and complexity. Development costs of fighter aircraft have increased by a factor of 100 over the last 40 years, and unit procurement costs have increased at an annual rate of 11 percent since 1963.
- Budgets for military aircraft procurement have decreased by approximately 50 percent since the FY87 peak and are expected to decrease further as the overall DoD budget declines. RDT&E accounts have also declined, though not by as much. Projections of budget levels over the next decade suggest that while there is pressure for industry consolidation in some form, there is no apparent reason to expect many prime contractors to exit the industry.
- The number of new military fixed-wing aircraft projects per decade has declined dramatically, from 49 in the 1950s to 7 in the 1980s. Three new designs have flown in the 1990s, and expectations are that perhaps one or two more will reach flight test status this decade.
- The financial health of the aircraft prime contractors appears reasonably good. Reasonable projections of future sales and profitability suggest that at least several firms will remain as prime contractors. Recent experience indicates the following:
  - Military aircraft sales decreased 27 percent from the 1986 peak but remain significantly higher than those of the mid-1970s. Though sales are expected to decrease, the product mix is

changing so that many of the firms are becoming less reliant on military aircraft sales.

— Various measures of profitability have declined from their mid-1980s peak but have not fallen below historical averages. Recent figures show some improvement.

— Corporate debt has increased substantially since 1984, but recent data indicate improvement. Much of this debt is related to commercial ventures, especially for Boeing and McDonnell Douglas.

— The number of active military aircraft divisions of the prime contractors has decreased rather slowly, from 20 in the 1950s to 10 in 1990s.

— Company-sponsored R&D increased slightly as a percentage of total sales but substantially in absolute value since the mid-1970s. Recent data indicate a moderate downward trend.

Though the picture is a mixed one, these trends do have important implications for future design capability. These are discussed in the next section.

# 4. IMPLICATIONS FOR DESIGN CAPABILITY

The trends presented in the previous section suggest two important sets of implications for design capability. First, budget and business base projections provide no apparent reason to expect a mass exodus of firms from the aircraft industry. There will be sufficient future spending on military aircraft to support several competitive design organizations. Second, the rapidly declining level of new design activity at each firm, together with the uncertainty of future production as a source of profits to pay for investments in design capability, raises questions about the strength and quality of design capability in the future. This section explores these issues in more detail.

## SLOW INDUSTRY CONSOLIDATION

With the decline in overall business base for the military aircraft companies since the mid-1980s, there has naturally been some concern that many companies would leave the business, thereby severely restricting opportunities for competition in the future. Based on the evidence presented in Section 3, we believe several design organizations will remain financially viable.

However, there is a distinction between "staying in the military aircraft business" and "maintaining a strong design organization." Traditionally, production activity has been the source of profits and overall financial health in the industry, while development activities have generally required long-term investment. Therefore, when considering if a firm is likely to stay in the aircraft business, we first look at prospects for production profits.

While projections of future government spending must remain speculative, it seems clear that some force modernization will continue and that at least a few production lines will remain active during the 1990s. Our current estimate is that the sum of Navy and Air Force spending for combat aircraft procurement should be in the neighborhood of $10 billion per year for the remainder of this decade. That is only about one-third of the spending rate achieved at the height of the 1980s buildup, and it clearly represents a substantial reduction in overall activity levels since then. However, it is about the same level of activity that sustained the industry throughout the mid-1970s, and since then three firms (Bell Aircraft, Fairchild-Republic, and LTV) have left the industry as prime contractors. The projected business base, therefore, does not seem inconsistent with the present industry size, measured in number of firms.

From the point of view of design capability and quality, a more important factor is that the number of aircraft programs is declining. We saw earlier that by the end of this decade, there might be only three designs in production. How can we reconcile that with the present industry of seven major firms, three of which have two aircraft divisions? The answer is that production activity has traditionally been distributed among firms, so that even if there are only three projects, the total business represented by those projects is likely to be distributed throughout the industry. Thus, while some firms may chose to leave the industry at the prime contractor level, several firms will remain.

There may, however, be some further consolidation in the industry during the next few years. Indeed, such consolidation has been under way. Virtually all of the prime contractors have been undergoing reorganizations and layoffs in an effort to reduce costs and improve their profitability. For example, Boeing merged six defense and space units into one division, Northrop sold a number of its facilities including its Century City headquarters building, and Lockheed has moved most of its Burbank, California, operations to Marietta, Georgia. All seven prime contractors have been laying off employees as their business base reduces. Further restructuring of this type will probably continue, especially in terms of eliminating excess manufacturing capacity.

Even assuming that several firms will stay in the military aircraft business in order to profit from production activity, it is less clear that they will continue to support their design activities to the extent necessary to maintain a full-system prime-contractor design capability. Two factors are important here. First, the firms will be less able to sustain the investment levels that design activities have required in the past simply because of the diminished level of the production business base. Second, the prospect of continuing reductions in military budgets increases the risk that subsequent production will not be large enough to justify the investment. Thus, it seems likely that long-term corporate investments for design activities and for sustaining the underlying technology development projects will come under increasing pressure over the next few years.

The evidence of such pressure is already apparent in the growing practice of teaming on new system development projects. While such teaming seems likely to alleviate some of the financial pressure of design activities, it might not solve some of the other difficulties caused by recent trends, as discussed below.

## THE THREAT TO DESIGN EXPERIENCE LEVEL

As noted in Section 2, aircraft design must continue to sustain a staff of experienced and skilled personnel. Furthermore, the underlying technology base must be sustained to advance the state of the art and provide the technical foundations for new designs. There is reason to believe that the level of design activity postulated for the next decade will not be sufficient to sustain an adequate level of staff experience and skills.

Two of the trends described in Section 3 directly affect design capability. One is the annual rate of new designs brought to the flight test stage, and the other is the number of firms active in such design and development activity.

Figure 4.1 shows the superposition of the numbers of active design organizations on the decade-by-decade display of the number of new aircraft design starts presented above in Figure 3.4. In this figure, a company is listed in italic type face if it was actively seeking design work during that decade but did not produce a new design that reached flight status. The numbers to the left of each firm indicate the number of new designs flown during that decade. The "T" notation indicates that the firm participated in a multicompany team on one or more projects during that decade, and the actual teaming linkages are indicated by the vertical lines to the right of the firm names. Finally, the vertical bars denoting the number of active firms are separated into two parts: The lower part signifies the number of parent firms, and the smaller upper part signifies the additional aircraft divisions contained within some of those parent firms. Hence, the total height of the bars signifies the total number of separate organizations engaged in design of military aircraft.

This figure shows that the number of firms producing new designs has declined over time but much more slowly than the rate of decline in new design activity. A corporate strategy of teaming has emerged in recent years as one response to the paucity of new design business.

The heart of the issue is whether the low rate of new design projects, spread over a relatively large number of firms, can provide continuity and a basis for accumulating the necessary experience in the art of design. One measure of design experience that seems useful is the ratio of the number of new design starts to the number of design or-

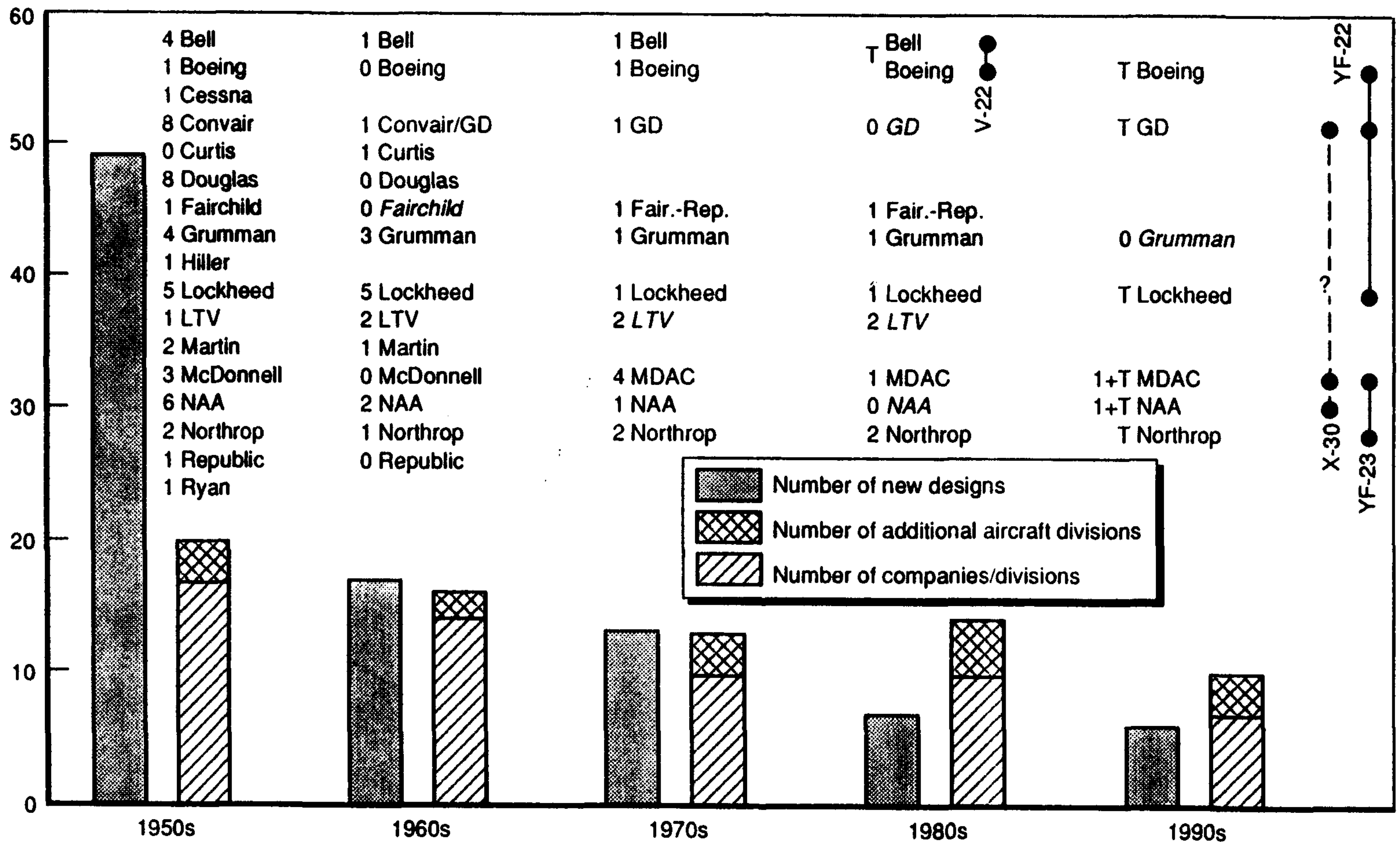



**Figure 4.1—Trend Comparison: New Designs and Number of Firms**

ganizations. With the data in Figure 4.1, the ratios for each decade were calculated and plotted in Figure 4.2. This ratio is a proxy measure of design experience. The figure shows the ratio has declined steadily, from approximately 2.5 designs per team per decade during the 1950s, to the present level of about one new design per team every *two* decades. Furthermore, the ratio seems likely to continue declining as a result of continuing budget constraints; the dashed lines in Figure 4.2 indicate the range of possible values for this ratio as we move into the next decade. As discussed previously, we can only hypothesize about the relationship between experience and quality, but we think for both intuitive and empirical reasons that the relationship is fairly strong.

Figure 4.3 illustrates a different perspective on the problem. It overlays a horizontal bar equal to the average career length for a typical engineer on a list of the new aircraft that were designed and flown in each decade. An engineer who began his career in the 1950s would have worked in an industry that developed and flew 84 new designs before he retired. An engineer who started in the 1960s will see only 40 new designs fly. The situation gets significantly worse with time.

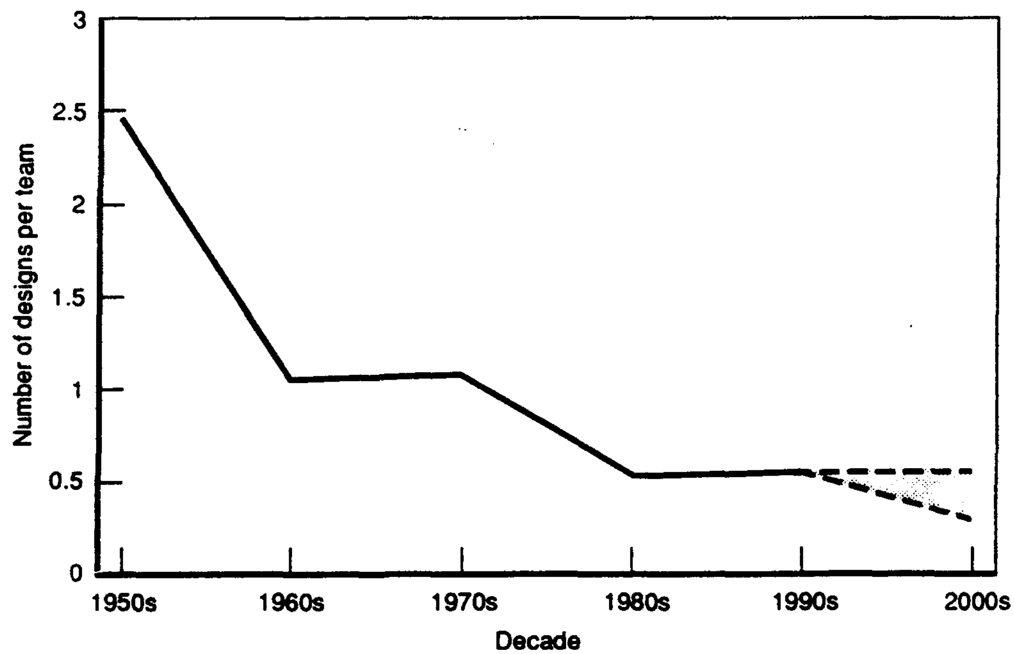



**Figure 4.2—Decline in Average Design Team Experience**

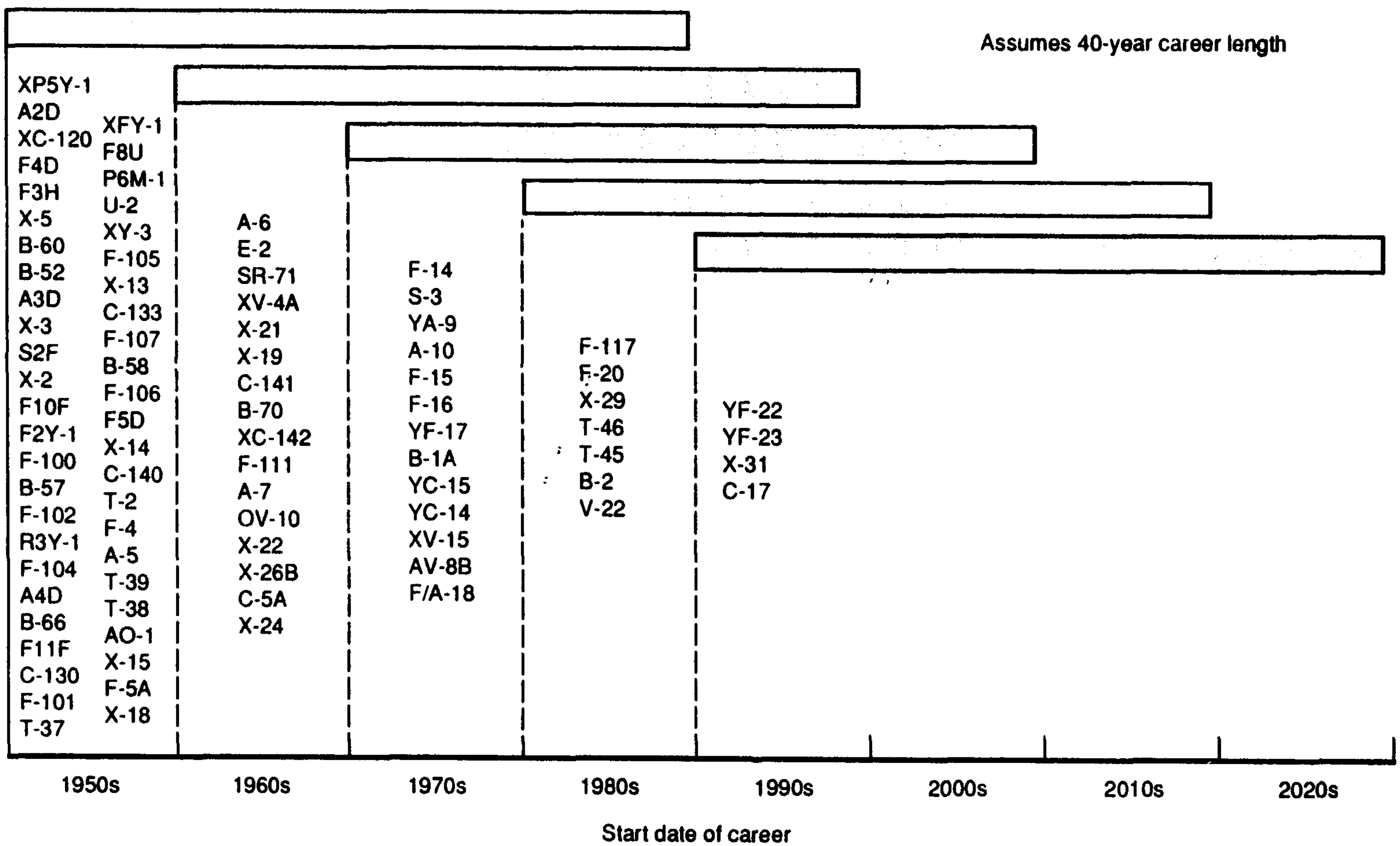



**Figure 4.3—Designer Career Length vs New Designs by Decade (1950–1990)**

The entry-level designers and engineers in the 1980s and 1990s will be the senior technical and management staff in the 2010s, and their scope and breadth of design experience will fall significantly short of the experience of today's senior technical staff. Furthermore, the future work environment for these engineers will lack the opportunity for cross-fertilization of ideas and knowledge between firms and projects.

Current industry managers are concerned that future senior technical staff will have designed only one aircraft in 20 years. The problem of an inadequate experience base is just now beginning to manifest itself, though the real effects will not be felt until the next decade. For instance, in the ATF competition, industry retained its retired senior technical managers as consultants, who then played a critical role in guiding the ATF design. Senior industry managers are already dissatisfied with the current experience level of their design engineers and have serious concerns about this problem in the future.

It should be noted that some of the experience obtained with other large complex systems (cruise missiles, satellites) is relevant to aircraft design. Similarly, there is some interchangeability of experience across military aircraft types and possibly even from commercial aircraft. However, we do not believe that this significantly resolves the problem. Most other military systems will also be facing the same sorts of problems, and, more to the point, expertise at designing and developing complex aircraft systems comes only from the direct experience of designing and developing such systems. That experience helps engineers and managers anticipate (and prevent) problems on their next project.

While maintaining an adequate experience base among future design engineers is a problem in itself, the introduction of new technologies complicates it. Three technologies have been introduced in the last decade: composite materials, large-scale integrated digital avionics, and low observables. Each of these technologies represents a radically different approach to aircraft design. Each adds complexity to the process and complexity to the resulting aircraft system. As a result, the system integration function performed by prime contractors is increasingly important. The capability to perform such system integration is largely gained through experience in designing aircraft systems that require such integration.

## SUMMARY

It seems clear that the military aircraft industry is entering a period of consolidation as military budgets decrease. However, the industry went through a similar period in the mid-1970s and emerged only slightly smaller than before. Furthermore, present budget projections indicate production budgets of several billion dollars per year throughout this decade. Since those budgets tend to get spread throughout the industry by associate contract and subcontract arrangements, it seems likely that at least several of the current prime contractors will have sufficient levels of business to support competing design organizations.

The cost of sustaining a design capability, even through several years without prime aircraft development contracts, is relatively small (e.g., $100 million annually, plus facilities) compared with the potential rewards that can be achieved through winning new system development and production contracts. We conclude that within the foreseeable future, the military aircraft industry will likely adopt some new strategies to reduce the cost and risk of competing for new development contracts but that it is unlikely that a major reduction in the number of firms able to compete for new design business will occur. In fact, when viewed from the perspective presented in the previous section, the opposite "danger" might be present: that the potential new design experience will be spread among too many competitors, resulting in a lower concentration of activity than desired to sustain a high level of experience and competence. It is the threat to design experience that we believe requires the attention of Air Force and DoD policymakers.

# 5. A FRAMEWORK FOR EVALUATING POLICY OPTIONS

The trends we documented in Section 3, and the implications of those trends that we drew in Section 4, suggest that future policy toward development of new weapon systems needs to be substantially different from that of the past. For the last three decades, the United States has devised and refined an acquisition policy that focused almost entirely on the creation of a few new weapon systems, each destined for quantity production and designed to strengthen U.S. military defense against a largely monolithic and well-defined enemy. Today, many of the logical underpinnings of that policy are being subjected to serious questioning. What seems beyond question is that in the near future, the budgets available for production of new weapon systems will be very much smaller than in the past decade.

In place of the major large-production programs of the past, there is a growing consensus that the future will involve some mix of the following activities:

- Continuing, but slower, modernization of the force. While a few aircraft production programs are expected to remain active through most of the 1990s (among the possibilities are the C-17, the B-2, the F-16 for both USAF and FMS, the F/A-18, and the T-45), even those lines are likely to be operated at somewhat less than historical rates. Production of new systems will be augmented by upgrading existing systems through replacement of mission equipment, extension of structure life, etc.
- Maintenance of an industrial base for possible future force expansion (reconstitution). This concept, while not yet well defined, seems likely to play an important part of the overall military-industrial policy as the active force becomes smaller and smaller.
- A continuing program to advance the underlying technology base and to provide system design options for the future, including the creation and demonstration of innovative new concepts, technologies, and systems.

At first glance, this view of the future might seem only slightly different from that of the recent past. What is truly different is that the anticipated production budgets and rate of new system design starts are expected to be inadequate to provide the historical levels of financial support for the technology base and the design process infrastructure. Cash flow and profits from large production programs have provided the economic foundation for these activities in the past. With that foundation diminishing, a concomitant diminishing of the technology base and design infrastructure is inevitable.

Does the United States need to sustain the technology base, design infrastructure, and activity levels of the recent past? Does it need to sustain ten full-service prime-contractor system design teams? Almost certainly not. But prudence demands that the country retain a national capability to design and develop new weapon systems to meet new contingencies as they arise. We cannot predict exactly what those new contingencies will be, but advancing across a broad spectrum of military technologies will better position the United States to meet such challenges. Future military technologies will certainly include some elements of aeronautical science, and those will at some point be drawn upon to develop and produce new aircraft weapon systems. It is the ability to respond to future contingencies in an effective manner that we must sustain.

Thus, the United States is in a period of major change, both for the national military posture and for the industry that serves it. We believe that one important issue during this period of change will be to retain an appropriate level and composition of aircraft design capability. As a first step in examining strategies to resolve that issue, it seems useful to summarize our view of what might constitute an "adequate" national capability for military aircraft design.

We suggest that an adequate national military aircraft design capability is characterized by the existence of a few design teams and associated organizations, each possessing the following attributes:

- A continuity of activity to enable learning by experience in a core group of key personnel, thus facilitating an accumulation of knowledge and experience necessary to undertake advancing levels of responsibility.
- A program of designing, building, and testing new aircraft concepts. Simulation is not enough; only actual construction and flight testing will demonstrate the strengths and weaknesses of each design and provide feedback to the designers so that they can build on that experience and apply the results to the next project.

We outlined in earlier sections some order-of-magnitude estimates of the historical minimum size of such design groups: $100 million in annual funding, 1000 engineers and technical managers, and necessary facilities. While future aircraft designs will not necessarily follow the pattern of "higher-faster-further" performance that has characterized the past several generations, it seems likely that new designs will draw heavily on advanced technologies. For example, one design might emphasize dramatically lowering production cost; another design might call for a very smart unmanned system in order to reduce casualties in high-threat situations. The point here is that just because some elements of the threat appear to be abating, the United States should not expect future aircraft weapon systems to be simple devices that can be designed by inexperienced teams. Nothing in the long history of warfare would support such expectations.

How might the United States move from the present posture to something approximating the envisioned new posture? There is a wide range of policy options. We will outline some of those options below. None is explored in detail here, nor is the list presented here meant to be comprehensive. Rather, our goal is to outline a framework for addressing these issues and to present some preliminary notions on their effects and feasibility.

## POLICY OPTIONS

The analysis of policy options involves two steps: (1) identify a range of possible options, and (2) evaluate each one across several indicators, at least to the extent necessary to provide some notion of which seem the most attractive.

A wide range of actions might be taken that would affect the quality of aircraft design capability. Table 5.1 provides a preliminary list of possible policy options. The list is not exhaustive, and we have only begun to explore the costs and effectiveness of these options. Implementation issues and implications for the Air Force have also not yet been fully addressed.

**Table 5.1**

**Examples of Policy Options**

- No action.
- Provide financial incentives for investment in design capability.
- Treat industry as a public utility.
- Encourage industry consolidation:
  — Temporary or permanent teaming arrangements.
  — Vertical restructuring.
  — Mergers and acquisitions.
  — Exit industry.
- Increase frequency of design activities.
  Strengthen government in-house capability.

At one extreme, the government might choose to take no action, letting industry respond to market forces and changes in the acquisition environment without help or guidance. Of course, the industry is continually evolving and exploring different strategies and organizations, as exemplified by the variety of teaming arrangements employed in recent design competitions. The risk here is that any restructuring that the industry undergoes as a response to market forces might not preserve those features that are necessary for a quality design capability, or it might not preserve them in a form that the Air Force would prefer. The rate of technological advance may slow, the performance of new aircraft may be less than desired or needed, and industry's ability to incorporate new technology into operational systems may become impaired. In addition, the time and resources required to reconstruct design capability would grow over the years, with implications for both the cost of new systems and the timeliness with which those systems can be designed and developed. A degradation in design capability implies increased inefficiencies in future aircraft development programs.

To affect the quality of design capability, the government would make changes in acquisition policies and procedures. For example, the DoD might adopt a policy of initiating a series of prototype designs so that industry designers would have more opportunities to practice their craft on a variety of design concepts. Alternatively, the government might assume a more active and critical role in aircraft design capability: Government labs could play a more active role in technology base work, or the government might operate design bureaus and/or production facilities. The former would involve labs in more technology development and application activities, including hardware development and testing. The latter might resemble the Navy's ship design capabilities. Again, the costs and benefits of such options have not yet been assessed. Such actions might be thought of as a change in the "demand side" of the equation.

The government (or the Air Force alone) might also choose to take some actions that would attempt to influence the "supply side" of the design process without changing the demand for new designs or other aspects of acquisition policy. For instance, the government might play a more active role in guiding industry consolidation, in terms of either number of firms or the structure of the industry.

This simple categorization scheme is not meant to imply that policy initiatives to strengthen design capability should be channeled along any one of these paths. In fact, it is clear that these categories of options are not mutually exclusive. For instance, any direct action that the government takes will affect market forces and industry's response to those forces. In some cases, the options are complementary: Encouraging industry consolidation (e.g., reducing the number of design organizations) and increasing the frequency of design activities would increase the experience base of remaining design organizations more than either option alone.

Defining a set of evaluation criteria that can be applied consistently across the range of options is difficult. At the most general level, there are three criteria: (1) the cost of the alternative, in terms of both direct expenditures and opportunity costs of finding those funds in a highly constrained budget environment; (2) the effectiveness of the option in addressing the various aspects of the problem (e.g., experience, financial viability, etc); and (3) the secondary effects resulting from implementing the policy option, such as effects on the technology base, long-term industry health, and applicability to other weapon system types.[1]

It is useful to briefly examine two policies that seem to be emerging: One is the suggested acquisition policy of supporting development of some "prototypes" that would not necessarily be taken through full engineering and manufacturing development (EMD), and the other is the growing industry practice of teaming, a form of industry consolidation. Each is discussed briefly below. Our purpose here is to illustrate important issues for further analysis, not carry out a full-scale evaluation.

## INCREASING DESIGN ACTIVITY RATES

The strategy of increasing design activity rates by facilitating some design and development programs without a production commitment has received considerable discussion in recent months, although details differ between proposals and few implementation problems have been resolved.[2] The policy would, however, be directly responsive to one of the problems outlined in early sections of this report: namely, too few new designs being started, with a resulting loss of design experience base.

Since increasing the number of designs is a fundamental element of this strategy, it is important to illustrate what is meant by design.

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[1]An ongoing research effort is oriented toward a fuller identification and evaluation of alternative strategies for maintaining the quality of design capability.

[2]See "A Revised Approach to Defense Acquisition," DoD White Paper, 4 March 1992; Congressman Les Aspin, "Tomorrow's Defense from Today's Industrial Base: Finding the Right Resource Strategy for a New Era," paper, 12 February 1992.

There is a wide range of possible design activities, each associated with a particular cost range, as illustrated in Figure 5.1.[3] Design activities range from rather small, inexpensive, narrowly focused technology demonstrators (such as the X-29 and X-31) to what we have called here preproduction test articles, which are essentially the same as full-scale EMD test articles. Each type of activity exercises a particular set of skills and imparts a certain level and type of experience to the design team. Maintenance of a fully capable, experienced design organization requires a mix of these different types of activities over time. That includes occasional production of a new aircraft design.

The acquisition strategy of the past few decades focuses on the third and fourth types of design activity listed in Figure 5.1: modifications to existing aircraft systems and new projects intended from the outset to continue through EMD to production and deployment. A policy to increase design activity rates without excessive additional budget allocations could be implemented by shifting the balance among design

| Type of design activity | Development cost range | Additional time to production |
|---|---|---|
| • Technology demonstration<br>– Narrow focus on one or two design issues<br>– Typically two flight vehicles for test program | \$200–400M | 4–6 yrs |
| • Operational demonstration<br>– Suitable for developmental and operational test<br>– Limited production, not fully engineered | \$500–2000M | 3–5 yrs |
| • Major modification<br>– Change to one or more critical subsystems<br>– Requires limited integration skills | \$500–3000M | — |
| • Preproduction test article<br>– Typical of present EMD programs | \$3–10B | 0 yrs |

**Figure 5.1—Range of Design Activities**

[3]The cost information was drawn from several existing databases at RAND, including one based on a survey of program managers and a literature review of information on prototyping, and another derived from *Selected Acquisition Reports*. The cost ranges shown are meant to be illustrative, and do not necessarily reflect the expected cost of any particular program.

program types to include technology and operational demonstrators. An *operational demonstration* involves production and fielding of a limited number of systems, with the results of operational use fed back into the design process. An interesting example of this, though not preplanned, was the deployment of the two JSTARS development test articles to the Persian Gulf.

Production engineering and producibility concerns are important aspects of design capability. Thus, some programs should continue to follow the current acquisition strategy of development followed by full-rate production. Other programs would focus on development. Some of these would include production engineering as part of the design activity. For instance, both operational demonstration and major modification programs include at least limited production.

In addition to having different costs, these options provide different levels of progress toward full production capability. For the technology demonstration and operational demonstration designs, a range of estimates is given for how long it would take to proceed from successful completion of the demonstration to production of a fully developed weapon system.[4] It is not meant to imply that such an additional step would be taken for each demonstration design, but such designs do make a contribution toward shortening the lead time to operational capability if that decision is made.

For purposes of illustration, and to get some idea of the financial consequences of this approach, we have generated several possible design activity mixes. Figure 5.2 summarizes both the mix of activities and an estimate of their total development costs. A mix of design activities over a given period of time seems best able to incorporate the range of skills and impart the range of experience needed to maintain a viable design organization. The costs of each mix were calculated using a reasonable cost within the cost range of each activity type shown in Figure 5.1.[5] We have included cost estimates of the several programs that will be active during the 1990s as a baseline totaling $30 billion. This includes the F-22 EMD phase (approximately $11 billion), the F/A-18 upgrade (about $4 billion), the AX (about $10 billion), and the MRF (about $5 billion based on a modified F-16). Adding various quantities of technology or operational demonstrators

[4] Note that the cost estimates given in the table do *not* include the cost of any additional development required to reach production status.

[5] Again, these costs are meant to be illustrative. Further analysis is required to improve the quality of these estimates.

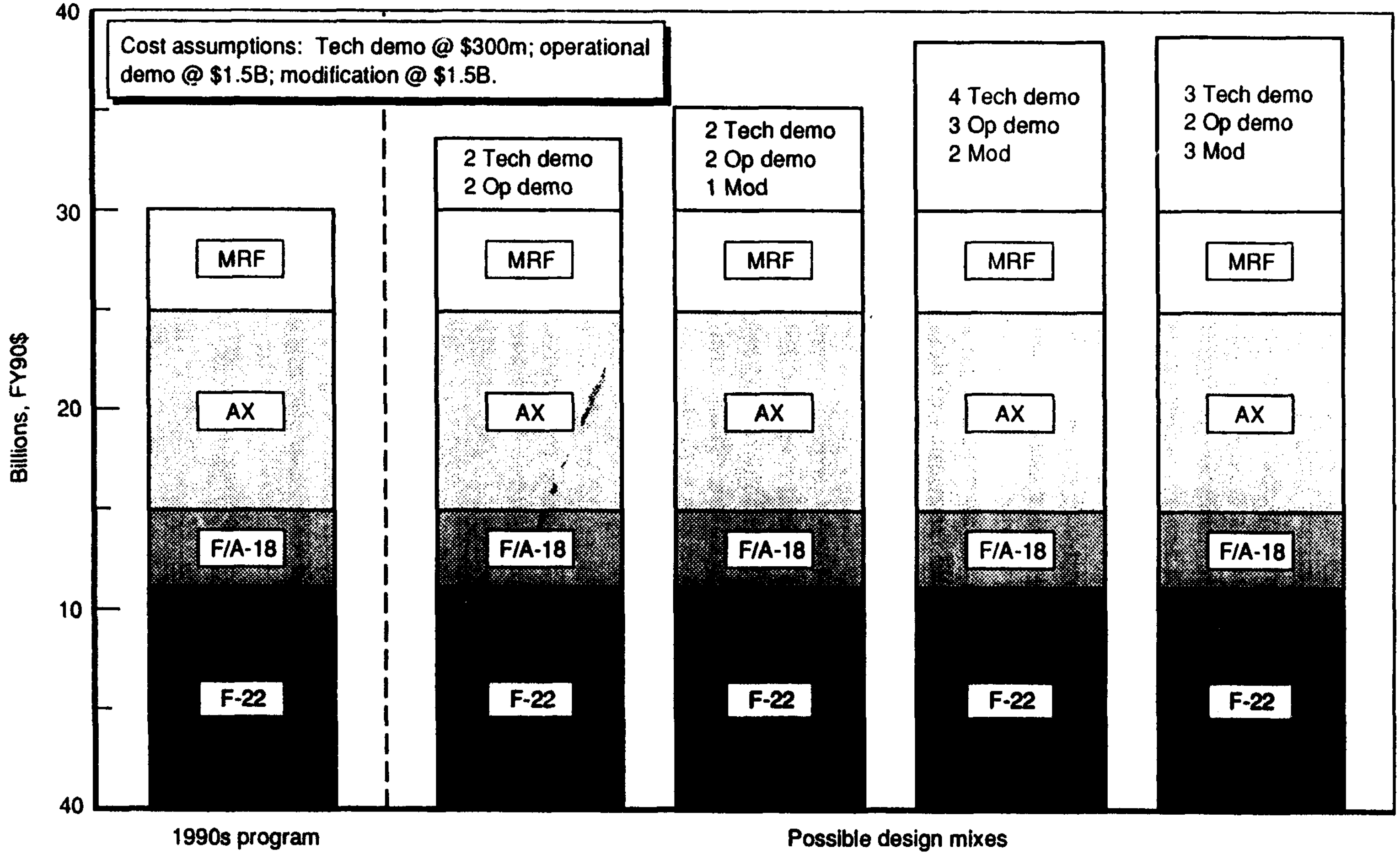


Figure 5.2—Budget Requirements for Alternative Mixes of Design Activities

could roughly double the total number of design projects for a 10 to 20 percent increment in budget.

The primary effect of increasing design activity rates is to significantly increase the design experience base. The extent to which design experience is increased is a function of both the level of increase in design activities and the number of design organizations. If many organizations are active, then the effect of increasing design activity would be less than it otherwise might be. Increasing the number of designs, together with industry consolidation, significantly increases the experience base in terms of designs per team. We think that an adequate number of designs per team per decade is probably between 1.5 and 2, several times higher than the current ratio (see Figure 4.3). To achieve this, the number of design organizations could be reduced to about five and the frequency of design activities increased to about ten per decade. Such changes would be a radical departure from current industry size and acquisition practice.

While perhaps the most direct way of increasing design experience and affecting the quality of design capability, increasing design activity rates seems particularly difficult, as it requires a shift in how both government and industry think about and conduct weapon system acquisition. Over the last several decades, acquisition policy and practice have been oriented toward filling specified force structure needs. A dominant and fairly well-defined threat meant that system performance requirements could be identified and agreed on prior to the start of development. Those programs that began development were almost always intended to continue into full-rate production and operation.

Increasing the frequency of new design starts would require a shift in development strategy. The key is to separate design and development from production and to encourage development programs with no immediate commitment to produce in quantity. This involves creating a different balance between developing and producing major systems oriented toward specific force structure needs, on the one hand, and generating options that address a wider range of uncertainty, on the other.

The link between development and production of major systems seems particularly important because resources committed to large programs intended for production cannot be used for other purposes, and the types of development activities required to prepare for full-rate production and operational deployment are costly. The linkage between development and production is illustrated in Figure 5.3,

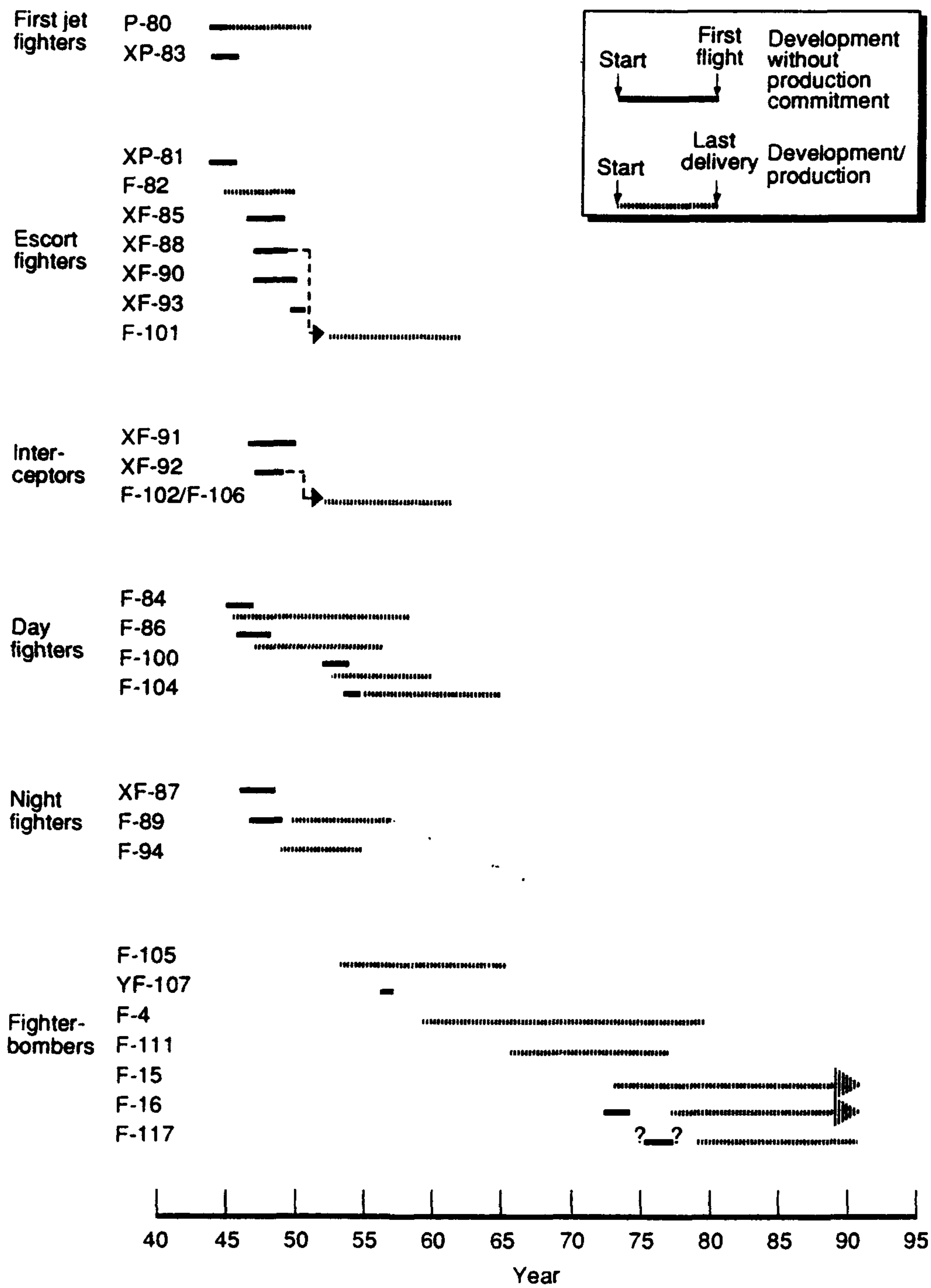


**Figure 5.3—Patterns of Air Force Fighter Aircraft Development**

which shows historical fighter aircraft development schedules for Air Force systems. Programs with both development and production focuses are shown. The distinction lies in whether a strong commitment to production was made at the time development began. Most development programs in the last few decades were intended for production. Increasing the frequency of design activities requires a return to a philosophy similar to that used during World War II, when many experimental aircraft were designed and tested with no commitment to production, because there was a need to explore alternatives in the face of uncertainty.

Several challenging implementation issues arise in thinking about the mechanics and the technical and political feasibilities of increasing design activity rates. These include:

- The efficacy of this option is predicated on substantial industry consolidation. There is neither the funding nor the military need to enable increased design activity rates at all of the current design organizations.
- Obtaining political support in both DoD and the Congress for development programs that are not committed to production.
- Creating an appropriate business environment, including incentives, profit, risk allocation, and contracting strategies. As discussed previously, profits earned on large production programs provide much of the motivation for firms to both stay in the aircraft business and invest scarce resources in technology and facilities. A business strategy that enables a firm to remain financially viable and invest in people, technology, and facilities while performing a series of design activities would need to be created. Such a strategy is fundamentally different from current acquisition practice.
- Defining and expressing requirements for development programs. In the past, a well-defined threat has guided both capability and force structure requirements. The current threat, while still evolving, is likely to be much more uncertain. Providing guidance for technology development and application in this new environment would be challenging.
- Demonstrating production readiness with development items. Producibility and production engineering are integral aspects of design capability. They involve translating a concept or technology demonstration into a producible and affordable operational aircraft. We currently do not understand how to achieve this without actually producing at least a few aircraft.

In spite of these challenges, this option deserves close consideration because of its relevance to other industry problems. Interestingly, earlier studies have recommended increasing design activity and encouraging a wider range of program types short of EMD and production to address such long-standing acquisition issues as maintenance of the technology base and hedging against uncertainty in the threat. Such a policy shift would also be applicable to other sectors of the defense industry that are suffering from a similar decline in the experience base, such as helicopters, submarines, tanks, and missile guidance systems. For these reasons, we recommend that this strategy be assessed more thoroughly for its feasibility, cost, and effectiveness.

## INDUSTRY TEAMING

One strategy the industry is currently adopting, with some encouragement from the DoD, is to join in various teaming arrangements when bidding on and performing major aircraft development projects. The concept of *teaming* has not been rigorously defined. As used here, teaming means that two or more firms, having similar product lines and levels of design/development capability, agree to jointly develop and produce a new product. The formal mechanism of teaming can take a wide variety of forms. At one extreme, a new joint-venture firm might be organized, with the contributions and responsibilities of each of the participating firms spelled out in the corporate charter. The government would then contract with that new firm. At the other extreme, the teaming mechanism might consist of a single firm serving as prime contractor to the client, with the other firms participating via subcontracts. The distinction between that form of teaming and the usual subcontracts with other suppliers is that the "team" members are similar organizations with similar product lines.

Figure 5.4 shows most of the new aircraft projects (both fixed and rotary wing) of the last decade and the teaming arrangements that have been adopted to support those projects.[6] One of these (A-12) has since been canceled, and the bottom five are all competitors on one project (the successor to the A-12). The figure presents a strong image of an industry that is forming and reforming teams of many different compositions, in response to evolving demands. In the 14 examples shown, only two teams appear twice: The MDAC/Northrop team developed the F/A-18 and the YF-23, while the Lockheed/

[6] Only a few major aircraft projects started since 1980 have not involved teaming, including the F-117, X-29, C-17, and P-7. The P-7 was canceled soon after it started.

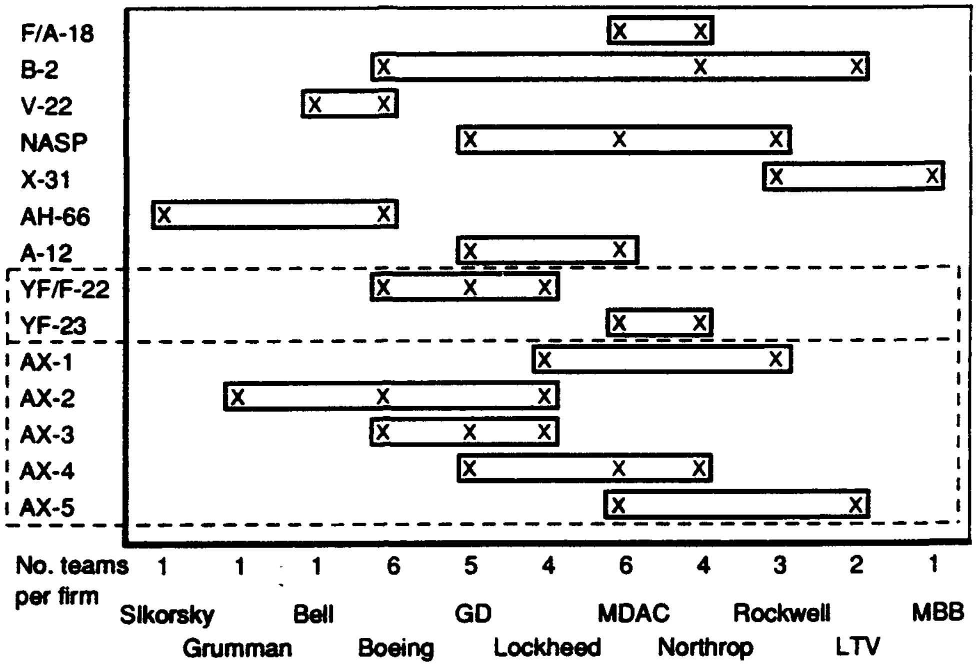


**Figure 5.4—Aircraft Acquisition Teams**

Boeing/GD team developed the YF/F-22 and is a competitor on the AX. Every other team appears only once.

It seems likely that this model of behavior will prevail for at least the immediate future. Thus, even if there is not a large number of formal mergers or exits from the industry, we might observe an *effective* consolidation through teaming.

There are a variety of important questions about the effects of teaming that remain unresolved. The basic issue is whether teaming of one form or another offers a mechanism for efficiently using resources to sustain a net, effective national design capability that can be responsive to a wide range of future Air Force needs. We do not currently know enough about the various frictions involved in forming and managing large teams on complex design activities to understand the effect on the overall level of capability that can be applied to new projects. Such issues should be resolved before teaming is accepted as a continuing strategy for coping with excess industry capacity.

## PRELIMINARY RECOMMENDATIONS

We have identified a risk to the quality of future design capability: Current and projected activity rates are too low to sustain an adequate experience base for a core group of technical managers and engineers within the existing design organizations. The problem is likely to worsen as budgets continue to decline, fewer programs are started, and excess design and production capacity remain in the industry. Market forces are likely to respond slowly because the cost of maintaining a design capability (approximately $100 million per year) is small relative to cash flows and the potential rewards of large production programs, few though they are. These conclusions imply that some government action is required in the near term to preserve an effective aircraft design capability.

At this time, we are not prepared to make specific recommendations for action; such recommendations require more thorough analysis and evaluation of a wider range of policy options than those provided here. Nonetheless, we can recommend several modest courses of action that will better prepare the Air Force to take action in the future.

- We have observed that while many acquisition policies affect design capability, none is *intended* to do so and there is no coordination between them with respect to such impacts. In lieu of a specific policy for maintaining design capability, we suggest increasing the visibility of the issue in acquisition policy and decision-making at both the Air Force and OSD levels. For instance, design capability considerations can be addressed in decisions of the Defense Acquisition Board.
- As industry begins to consolidate and contract, the government should not impede industry restructuring and downsizing. Firms in financial difficulty that are considering exiting the industry should not be "bailed out."
- Both the Air Force and DoD in general should explore more specific and effective policy options designed to strengthen design capability.

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